PHYSICAL FACTORS INFLUENCING THE THROWING ACTION IN NETBALL AND CRICKET PLAYERS

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DECLARATION

I, the undersigned, hereby declare that the work contained in the thesis is my own original work and has not been previously, as a part or as a whole, been submitted at any other university with the aim of obtaining a degree.

Signed ___________________________ Date ________________
To my Parents
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SUMMARY

The ability to execute a powerful throw is an essential skill for netball and cricket players. Numerous accurate, powerful throws are being made during the course of a match. It is thus necessary to focus on the development of excellent technique, as well as the development of the physical aspects that might contribute to the effectiveness and efficiency of the throwing action. The aim of the study was to determine which specific physical factors play a significant role in the distance that netball and cricket players can throw a ball. The distance of the thrown ball was also seen as an indirect measure of the power with which the throw was executed, with a greater distance implying more power.

A group of volunteer subjects was drawn from the local netball and cricket clubs from the Stellenbosch area. Thirty nine injury-free, club level subjects participated in the study, of whom twelve (n=12) were male and twenty four (n=24) were female. Various physical factors were selected that give an indication of its contribution to a powerful throw for distance. Range of motion assessments involved the range of the shoulder joint, as well as the elbow joint, wrist joint and the back. The strength of the internal rotators was compared to the strength of the external rotators in the shoulder joint. Core stability was assessed by doing two different tests, with one involving shoulder stability as well. The relationship between upper-limb length and the throwing distance was assessed. Various anthropometric measurements were done, including height, weight, skinfolds, and the “wing span”.

Throwing for distance was measured while the subjects remained seated on a chair. This throwing position was chosen in an attempt to eliminate the contribution of the kinetic chain that generates momentum in the lower extremities which get transferred to the upper extremities. It was thus an attempt to only focus on the involvement of the upper extremities. This seated throwing position is also often used as a test for throwing ability in athletes. Throwing for distance was also done with the subject strapped onto the chair to exclude the involvement of the core in the transfer or generation of energy.
Results from this study showed that there were very few physical factors that had significant correlations in both groups. In the cricket players, factors from the isokinetic testing played a significant roll, but not in the netball players. There was a significant correlation which was positive with the average peak torque concentric/concentric 180 degrees/second with external rotation seated on the chair ($r=0.46; p=0.03$). There is also a tendency towards a significant correlation when the subject was seated in average peak torque concentric/concentric at 90 degrees/second both with internal ($r=0.52; p=0.06$) and external rotation ($r=0.62; p=0.05$). The peak torque concentric/concentric at 90 degrees/second during external rotation ($r=0.61; p=0.06$) and the peak torque concentric/concentric at 90 degrees/second during internal rotation ($r=0.49; p=0.06$). Both tended to a correlation but were not significant. There was found to be a few positive and statistical significant factors the average power concentric/concentric contractions at 90 degrees/second during external rotation when seated on the chair ($r=0.64$ and $p=0.03$) and average power concentric/concentric contractions at 180 degrees/second during external rotation when seated on chair ($r=0.58; p=0.04$) as well as strapped in on chair ($r=0.06; p=0.03$). It cannot be concluded there are any specific physical factors that would influence the distance thrown in both the netball and the cricket players. It can thus be assumed that a number of other factors might play a more important role in the execution of a powerful throw for distance, such as the involvement of the total well-coordinated kinetic chain, and the throwing techniques.
OPSOMMING

Die vermoë om ‘n harde en akkurate gooi uit te voer is ‘n essensiële vaardigheid vir netbal- en krieketspelers. ‘n Groot aantal harde gooie word gedurende die loop van ‘n wedstyd uitgevoer. Dit is dus noodsaaklik om te fokus op die ontwikkeling van die gooitegniek, maar ook op die ontwikkeling van fisieke aspekte wat moontlik ‘n bydrae kan lewer tot die effektiwiteit van die gooie-aksie. Die doel van die studie was om te bepaal watter spesifieke fisieke faktore ‘n rol speel in die afstand wat die netball en krieketspeler kan gooie. Die afstand van die gooie is ook beskou as ‘n indirekte meting van die krag waarmee gegooi is, met ‘n groter afstand wat meer krag sou impliseer.

‘n Groep vrywilliger subjekte van plaaslike netbal- en krieketklubs in die Stellenbosch omgewing het aan die studie deelgeneem. Nege -en-dertig beseringsvrye, manlike (n=12) and vroulike (n=24) proefpersone, wat op klubvlak speel, het aan die studie deelgeneem. ‘n Verskeidenheid fisieke faktore was moontlik die gooi-afstand kan beïvloed, is getoets. Omvang van beweging van die skouer gewrig, sowel as die elmboog, gewrig en rug is geassesseer. Die krag van die interne rotator spiere is vergelyk met die eksterne rotator spiere. “Kernstabiliteit” is bepaal deur twee verskillende toetse, met een toets wat ook skouerstabiliteit betrek het. Die lengte van die boonste ledemate is vergelyk met die afstand wat gegooi is. Daar is ook ‘n verskidenheid antropometriese meetings gedoen, wat lengte, gewig, velvoue, en die “vlerk span” ingesluit het.

Gooi vir afstand is gemeet met die atleet in ‘n sittende posisie. As gevolg van die kinetiese ketting wat ‘n invloed het op die gooie aksie deur energie-oordrag van die onderste ledemate na die boonste ledemate, is daar besluit om die boonste ledemate te isoleer vir die gooie-aksie. Hierdie sittende toets word ook dikwels aangewend in die toetsing van atlete se gooivermoë. Die gooie vir afstand is ook gemeet met die persoon vasmekaan aan die stoel. Die rede hiervoor was om die rol van die “kernstabiliteitspier” in die oordrag van energie uit te skakel.
Resultate van die studie toon aan dat daar geen fisieke faktore is was `n merkwaardige beduidende korrelasie gehad het in beide die groep om te sê dat dit werklik `n rol gaan speel in verbetering van die goo-afstand nie. By die krieketspelers het resultate van verskeie isokinetiese toetsings `n betekenisvolle rol gespeel in die afstand was gegooi was, maar nie dieselfde vir die netbalgroep nie. Daar was `n beduidende korrelasie was positief was met die gemiddelde maksimum wringkrag konsentries/ konsentries 180 grade/sekunde met eksterne rotasie, waar die proefpersoon sittend is op die stoel ($r=0.46; p=0.03$). Daar is ook `n geneigtheid na `n beduidende korrelasie waar die proefpersoon ook sittend was by gemiddelde maksimum wringkrag konsentries/konsentries 90 grade/sekonde by beide interne ($r=0.52; p=0.06$) en eksterne rotasie ($r=0.62; p=0.05$).

Die maksimale wringkrag konsentries/konsentries 90 grade/sekonde gedurende eksterne rotasie ($r=0.61; p=0.06$) en die maksimum wringkrag konsentries/ konsentries 90 grade/sekonde gedurende interne rotasie was ($r=0.49; p=0.06$), beide neig na korrelasies maar is nie statisties beduidend nie. Dit was gevind dat slegs `n paar positiewe korrelasies was ook statisties beduidend was by die gemiddelde krag konsentries/ konsentries 90 grade/sekonde gedurende eksterne rotasie wanneer sittend op die stoel was ($r=0.64$ and $p=0.03$) en die gemiddelde krag konsentries/ konsentries 180 grade/sekonde gedurende eksterne rotasie sittend ($r=0.57$ en $p=0.01$), die gemiddelde krag konsentries/ konsentries 90 grade/sekonde met interne rotasie beide sittend ($r=0.58; p=0.04$) sowel as terwyl die proefpersoon vas gemaak was ($r=0.06; p=0.03$).

Dus kan ons tot die gevolgtrekking kom dat nie een van die fisieke faktore wat getoets was, `n invloed gehad het op die afstand gegooi is in beide die netball-en krieketgroep nie. Die gevolgtrekking is dat daar ander faktore is wat waarskynlik `n groter rol speel in die effektiwiteit van die goo. Van die aspekte kan die rol van die kinetiese ketting wees, asook die belangrike rol van `n goeie gooitegniek.
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CHAPTER ONE

PROBLEM SETTING AND PURPOSE OF THE STUDY

A. INTRODUCTION

To be a successful netball or cricket player, it is necessary for the athlete to be capable of throwing the ball with power and accuracy from one point to the next point of play. Although cricket and netball have different throwing techniques, the same muscle actions are used in the throwing action. It is possible that the physical factors chosen to be investigated in this study might in some way affect the powerful throw in both the netball and the cricket players (Luttgens & Hamilton, 1997).

An effective throw is the result of a combination of good technique and the contribution of several physical factors, including core stability, range of motion, limb length, anthropometric measurements, and isokinetic factors. In this study the effect of selected physical factors on the distance of the throw or power generation was investigated. There are a considerable number of different joints involved in throwing, but for the purpose of the study the focus was on the upper extremities, and more specifically the shoulder complex. If the physical factors do not play a significant role in the throwing motion, the technique involved might be the most important aspect for a successful throw. Technique does indeed play a major role in the throwing motion, but by not focusing on the technique and eliminating the kinetic chain, this could then provide an indication of how important the relevant physical factors are.

The aim of the study was to assess the role of selected physical factors that may affect effective and efficient throwing. These factors could be addressed during training to improve a “weak” throw. Thus an improvement of these physical factors could lead to improved results while throwing. On the other hand, if it is found that there is little or no correlation between the different factors tested, one could then suggest that the technique of these athletes should rather be investigated, and be focused on in
training. There are numerous physical factors involved in the throwing motion. For the purpose of this study the contribution of range of motion, core stability, anthropometry, distance throwing, and isokinetic factors were assessed. The involvement of the lower limbs was excluded with the focus solely on the contribution of the upper limbs and trunk. The kinetic chain of energy transfer was thus not taken into account, because of its contribution to the throwing technique when incorporating the lower limbs.

Previous studies on the role of physical factors focused mainly on baseball, tennis and volleyball. Not many studies have been undertaken on the role of the physical factors involved in throwing in cricket and netball players, or on the relevant throwing technique. The involvement of core stability in effective throwing is also a factor that has not been investigated in previous studies. This is probably because of the difficulty in measuring this aspect, and the lack of valid and reliable field tests to assess core stability in athletes.

This study was guided by a study done with tennis players by Cohen et al. (1994), involving 40 tennis players (average age 33 years). A physical analysis of the players was undertaken, which included height, weight, body fat percentage, generalised joint laxity, upper extremity range of motion, and the wingspan. Average height of the players was 1.8 metres (ranging from 1.58m to 1.94 m) and the average weight 82 kg (ranging from 69 to 129 kg). Serve velocity was also tested, as well as analysing the serve technique. Isokinetic shoulder evaluation was done in the scapula plane at 60 and 180°/sec. When comparing the dominant and the non-dominant extremities, it was found that there was no statistical difference (p<0.05) between the two extremities in wrist flexion, forearm pronation, elbow extension, glenohumeral abduction, vertebral measurements of shoulder rotation and shoulder internal rotation at 0° and 90° of abduction. A correlation matrix was calculated for serve velocity versus all the other data obtained, which included the demographic data, flexibility data, laxity data, and isokinetic data. This analysis revealed that the factors with the highest correlation was age, wrist flexion (both dominant and non-dominant), elbow extension torque, dominant shoulder flexion, dominant shoulder internal rotation at 0° of abduction and all measurements of shoulder torque production. Regression tables
were also compiled comparing the serve velocity to the measurements that had a higher correlation. The wrist flexion and elbow extension torque production was found to have a high relationship to the serve velocity (p<0.01), while the dominant shoulder flexion was less strongly related (p<0.05) to the velocity. The athlete’s age was found to have an inverse high relation to the velocity of the serves (p<0.05).

This study duplicated some of the aspects from the study by Cohen et al. (1994) for application to netball and cricket players, using the overhead action in performing the throw. A major difference was the unavailability of sophisticated equipment to perform the biomechanical analysis of the throwing motion, or calculating the speed of the ball after release.

B. PURPOSE OF THE STUDY

Throwing plays an important role in cricket and netball, and the faster and/or further the ball is thrown, the better. If an athlete’s throwing is impaired, it puts him/her at a disadvantage when compared to other athletes with better throwing power.

The purpose of this study was to assess the contribution of selected physical factors to a throw for distance amongst cricket and netball players. This could then give an indication of the physical factors that should be focused on if an athlete has a problem in throwing for distance. Improving the physical factors, should thus lead to an improvement in throwing distance. If it is found that the physical factors did not play a significant role in the distance achieved, it could be assumed that the technique used by the athlete played a major role.
C. RESEARCH QUESTIONS

The aim of the study was to determine the contribution of selected physical factors involved in throwing at club-level cricket and netball players.

The study addressed the following research questions:

- Which physical factors are the most important in throwing for distance in netball and cricket players?
- Does the club-level netball and cricket player need a strong core for throwing for distance?
- Does an increase in range of motion for the abducted shoulder position lead to an increase in power?
- Does the upper-limb length of the netball and cricket player play a role in the power generated, and distance thrown?

D. METHODOLOGY

Subjects (n=39) were drawn from the netball and cricket clubs in the Stellenbosch region. The skill level of the subjects ranged from the fifth team at club level to national level of participation. All subjects had to be injury free with no operations on, or pain in the dominant shoulder, participate at least at club level and higher, and over the age of 18 years.

Various assessments were made to determine the relationship between the different physical factors and the distance the ball was thrown. A questionnaire was completed to obtain a general background on the health, injuries, physical training, and demographic information of the participants.
E. LIMITATIONS

- The subjects volunteered to take part in the study and only a limited number of athletes eventually participated in the project.
- All the athletes who commenced with the project did not complete all tests and therefore the sample size in some instances was small.
- The speed of the ball could not be measured because of a limitation in the equipment. Thus, the distance thrown was used as secondary indication of the power and speed involved in the throw.
- The anthropometric testing was done before other testing which can be seen to change the outcome of the skinfold results (although not used at the end).

F. DEFINITIONS

**Acceleration:** The rate at which velocity changes (Luttgens & Hamilton, 1997).

**Agonis:** Muscle primarily responsible for motion; prime mover (Luttgens & Hamilton, 1997).

**Average peak torque:** This gives an average of the peak torque of each repetition thus indicates more accurately the average of the test values (Davies et al., 2000).

**Average Power:** Total work divided by the time it takes to perform the work (Davies et al., 2000).

**Concentric muscle action:** Development of muscle tension while the origin and insertion of the muscle approach each other, often referred to as positive work (Ellenbecker et al., 1988).

**Deceleration:** The rate at which velocity decreases (Luttgens & Hamilton, 1997).
Eccentric contraction: A lengthening muscle contraction (Luttgens & Hamilton, 1997).

Eccentric force: An “off-centre” force, one that is not in line with the centre of gravity or the axis and, therefore, tends to cause rotation (Luttgens & Hamilton, 1997).

Eccentric muscle action: Development of muscle tension while the origin and insertion of the muscle move away from each other, often referred to as negative work (Ellenbecker et al., 1988).

Eccentric/concentric ratios: Many functional activities use this muscle action pattern. In throwing, there is an eccentric action followed immediately by a concentric action of the glenohumeral internal rotators. This occurs in the cocking phase to acceleration phase of throwing (Davies et al., 2000).

Isokinetic: Exercise with an accommodating resistance and a fixed speed (Davies et al., 2000).

Peak torque: Peak torque may be defined as the maximum torque produced by the shoulder at any point through the range the arm is moving (Warner et al., 1990).

Peak torque to body weight: The total amount of work that is produced based on the number of repetitions (Davies et al., 2000).

Peak torque to body weight (Normalised data): Comparing torque to body weight (BW) adds another dimension in interpreting test results. Often, even through a subject has bilateral symmetry and normal unilateral ratios; the torque/body weight ratio is altered. One evaluates torque to body weight, rather than to lean body weight because an individual has to function with the total body weight and not just lean body weight (Davies et al., 2000).
Power: Work per unit time; that is power = (f x d)/t (f=force; d=distance; t=time), usually reported in units of watts (Davies et al., 2000), or the rate at which work is done (Luttgens & Hamilton, 1997).

Speed: Scalar quantity quantifying the rate of motion (Luttgens & Hamilton, 1997).

Torque: A force that produces or tends to produce a rotation about a point of axis, usually measured in units of Newton-metres (Nm) or foot-pounds (often used as a synonym for moment, which is the tendency or measure of tendency to produce motion, especially about a point or axis) (Davies et al., 2000; Luttgens & Hamilton, 1997).

Total work: This is a more quantitative measure of the strength of the muscles than merely considering the peak torque measurement. The measurement of total work is the product of the work done and the distance covered (Warner, et al., 1990).

Unilateral ratios (agonist/antagonist ratio): Comparing the relationship between the agonist and the antagonist muscles may identify weaknesses in certain muscle groups. This parameter is particularly important to assess when doing velocity spectrum testing because the percentage relationship of the muscles changes with changing speeds in many muscle groups. Application of this information may be important for athletes who need the advantage of muscular contractions with various activities. There may also be instances where it is preferred to have a dominant muscle group to enhance performance (Davies et al., 2000).

Work: Force acting through a distance; that is work = f x d, usually reported in units of Newton-metres (Nm = joules), or the product of a force and the distance over which that force produces motion (Luttgens & Hamilton, 1997; Davies et al., 2000).
G. STATISTICAL PROCEDURES

For the final relationship between throwing distance and all the various parameters measured, a correlation analysis was done. Because of weight significantly influencing throwing distance, it was decided to also perform a regression analysis where each of the measured variables were used together with body mass as predictor variable.

H. CHAPTER OUTLINE

In chapter two an overview of relevant literature applicable to this study is provided. This refers to the anatomy and biomechanics of the shoulder, the throwing technique, the characteristics of netball and cricket, and the different physical factors involved. The research methodology is described in chapter three. Here a description is given of the different measurements done and the protocols. The analysis of the data is discussed in the form of tables and figures in the fourth chapter with a discussion on the data obtained. The fifth chapter contains the conclusions, as well as recommendations for future research in this specific area.
A. INTRODUCTION

Netball, as well as cricket, are both sports where the overhead action is used for throwing the ball. Despite minor differences in the technique within the various sports, the basic throwing action remains inherently the same (Luttgens & Hamilton, 1997). As with baseball, throwing velocity is a necessary requirement for an effective throw, but it also plays an important role in players’ offensive performance if their throwing velocity can be improved and applied effectively within the team’s attacking strategies (Derenne et al., 2001).

In this chapter an overview is given of some factors that might affect the throwing action. Other research studies which focused on the various physical factors under investigation are also discussed.

Research that has been done on the throwing action and the shoulder complex, focused mainly on isokinetic testing, and the ratio of the internal shoulder rotators to the external shoulder rotators in the generation of power. Clements et al. (2001a) compared throwing performance in adolescents to investigate the adaptive changes that take place with repetitive throwing. Fourteen elite adolescent baseball players (13–16 years) and 14 age-, height- and weight-matched control subjects were assessed. Measurements included range of motion, isometric muscle strength, and overhead throwing speed. The researchers found no significant difference in shoulder or elbow joint range of motion, though there was a significant increase in pronation (p=0.03) in the baseball group when compared to their controls. There was no significant difference in shoulder and elbow isometric muscle strength between the groups, however the baseball players threw the ball approximately 50% faster than the control subjects. It was concluded that high throwing speeds may be achieved in
well-trained early adolescent baseball players without any changes in their isokinetic muscle strength, and with changes in only some of the range of motion measurements done.

The role that the capsular ligaments play in the internal and external rotation of the humerus was investigated by Branch (1995), while Hirashima et al. (2002) investigated muscle activity and their functional role during the throwing action. Branch (1995) studied six cadaveric shoulders (three right and three left) to measure internal and external rotation of the humerus, and the lengths of the anterior and posterior components of the glenohumeral capsuloligamentous complex. Results showed that the length of the anterior component of the glenohumeral capsuloligamentous complex dominated in external rotation of the humerus, while the length of the posterior component dominated in internal rotation. It can thus be said that the anterior and posterior components play a common role in limiting rotation at a number of sites in the shoulder complex.

A study on isokinetic performance and shoulder mobility focused on the relationship between these two factors (Wang et al., 2004). The study by Wang et al. (2004) determined whether arm dominance, or gender, played a role in shoulder mobility and strength in elite junior volleyball players. Eleven boys and twelve girls who played for the Taiwanese national junior volleyball team during the 2001 – 2002 season participated in the study. The results showed effects of both dominance (p=0.001) and gender (p=0.02) on the range of shoulder internal rotation. In the boys it was found that the range of motion of internal rotation on the dominant side was less than that of the non-dominant side (p=0.000). An effect of the gender was also demonstrated in the strength testing (p=0.000). There was greater shoulder strength in the boys than in the girls at both speeds (p=0.000), except for the internal rotation concentric (p=0.02) and eccentric (p=0.21) strength of the dominant arm at 180º/sec. When comparing the dominant and the non-dominant sides, a decrease in mobility in the dominant side in the boys was found.
Studies by Stanley et al. (2004) and Brown et al. (1988) both focused on shoulder strength and ROM. Brown et al. (1988) compared range of motion and isokinetic strength of the internal and external shoulder rotators. In the study by Stanley et al. (2004) the strength, passive range of motion, and shoulder internal/external rotation of the dominant and non-dominant shoulders of 51 adult female amateur tennis players (average 45 years) were compared. The authors concluded that the range of motion and strength adaptations widely reported in highly skilled tennis players were not apparent in amateur female players. Forty-one professional baseball players (average age 27 years) were tested in the study by Brown et al. (1988). Significant differences were found between the range of motion of the dominant and non-dominant arm of pitchers and position players.

Muscle strength and throwing speed in adolescents were assessed (Clements et al., 2001b), and an EMG analysis of the throwing shoulder was undertaken to observe muscle actions during throwing (Jobe et al., 1983). Clements et al. (2001b) wanted to determine if upper limb muscle strength correlated with throwing speed in adolescent baseball players. Eighteen elite adolescent baseball players (aged 13–16 years) participated in the study. The subjects underwent throwing speed tests and shoulder and elbow isometric, concentric and eccentric strength tests on an isokinetic dynamometer. It was found that 71% of the variation in throwing speed in these adolescent baseball players was explained by isometric internal rotation and concentric elbow extension torque-to-body weight in approximately equal proportions. The researchers concluded that both elbow extensor and shoulder internal rotation strength has a large influence on throwing speed. Therefore, preferential strength training for elbow extension and shoulder internal rotation muscle groups in adolescents was recommended, without neglecting the antagonistic muscle groups. Jobe et al. (1983) analysed five male subjects’ throwing and pitching motions, using dynamic electromyography and high speed photography. By inserting electrodes into the deltoid and rotator cuff muscles, the researchers attempted to define muscle activation patterns during the throwing and pitching cycle. During the wind-up phase there was no consistent pattern. During the cocking phase there was a sequential muscle activation pattern of first deltoid activity, followed by the supraspinatus, infraspinatus, and teres minor muscles, and finally the subscapularis.
During the acceleration phase there was a lack of muscle activity, even though the arm was accelerating forward in space. The follow-through phase was the most active stage with all the muscles firing intensely to decelerate the arm.

In a study by Ellenbecker and Mattalino (1997), shoulder internal and external rotation strength was evaluated by isokinetic testing, using concentric contractions. One hundred and twenty five injury-free professional baseball pitchers (aged between 18 and 34) volunteered to participate in this study. No significant difference was found between the dominant and non-dominant shoulder for external peak torque or single repetition work at testing speeds. Significant greater (p<0.001) dominant arm shoulder internal rotation was measured for both peak torque and single repetition work at 210 and 300°/sec, compared to the non-dominant extremity.

The chain of actions that causes the transfer of the truncal torque to the projectile velocities was described by both Perry (1983) and Pappas et al. (1985). They stated that the internal shoulder rotators power the motion of throwing, and act in the stabilisation of the glenohumeral joint during the transfer of torque when attempting to throw a ball.

No studies could be found on the role of core stability in the throwing action, or the role of core stability in the distance achieved through the overhead throw.

B. NETBALL

Netball is a game played competitively by female as well as male athletes. A team is constituted by seven individual positions and structured to provide playing units consisting of defenders, centre-court players and attackers. These positions then have specified areas on the court in which they may move (Bell et al., 1994).

Netball is a fast, skillful team game that requires running, jumping, throwing, catching, and shooting skills to score a goal. The teams may include up to twelve
players, but only seven may take to the court at any one time. Each player has a
playing position, determined by the areas on the court where she is allowed to move
(www.netball.org/thesport.htm).

There is limited scientific literature available on netball players, and especially the
throwing action in netball players, as confirmed by Bell et al. (1994). The
anthropometric profile of netball players in the various positions was analysed, and it
was found that the mean age of the subjects was 18.9±1.15 years. Bell et al. (1994)
also assessed the height and body mass of the players in the different playing
positions. Defenders had a height of 174.5cm±4.0, the centres were 163.9cm±5.6, and
the attackers were 173.4cm±4.5. The defenders had a body mass of 68.9kg±4.9, the
centres had a mass of 60.1kg±4.9, and the attackers were 64.7 kg±8.0.

The major aim of the game is to score as many goals as possible from within the goal
circle, which is a semi-circle centred on the goal line, measuring 4.9 metres in radius.
Only two players from each team may enter this goal circle and are allowed to score
goals, namely the goal attack and goal shooter (www.netball.org/thesport.htm). To
score a goal, the ball must be thrown through a 3.05 m high, horizontal ring that has
no backboard. The goal attempt may be defended by the other side’s players
(http://www. answers.com). The ball with which the game is played is made of leather
or rubber. It weighs approximately 400-450 grams, with a circumference of 690-710
mm. The court is 30.5 metres long, and 15.25 metres wide, divided into thirds. In the
centre third there is a centre circle with a diameter of 0.9 metres, and two goal circles
in both thirds, measuring 4.9 metres in radius, as shown in Figure 2.1
(www.netball.org/thesport.htm).
A netball player makes a large number of passes during a 60-minute game. Steele and Chad (1992) reported the average number of passes for each playing position as follows: goal shooter, 65.3; goal attack, 76.3; wing attack, 113.3; centre, 103.0; wing defence, 41.3; goal defence, 58.5, and goal keeper, 56.8. This adds up to an average of 514 passes in one game, which emphasises the importance of the throwing action for netball players.

C. CRICKET

Cricket is played by two teams of eleven players in each team. The game has no specific time limit; and depends on the type of game played. A cricket game may last from an afternoon to several days. The fielding team has all eleven players on the field, with two players going out to bat for the batting team. The game progresses by the bowling of balls (cricket@ida.com.au).

The sequence of events that constitutes a match follows: The fielding team spreads out around the field, to positions designed to stop runs being scored or to dismiss the
batsmen (cricket@ida.com.au). In the middle of the cricket field, usually aligned along the long axis of the ellipse, is a hard, flat strip of dry ground around 18 metres long, which is called the cricket pitch, preparation of this pitch requires skill and dedication (Hassan et al., 2003). There are two batsmen on the pitch at a time, both at different ends of the pitch, with one facing the delivery of the ball from the bowler and the other away from the bowler’s delivery. The bowler then runs up to the pitch where he bowls the ball over arm (http://angielski.co.uk/cricket_rules.htm).

The size of a cricket field varies and is roughly an elliptical field of flat grass, ranging in size from about 90 to 150 metres across, bounded by an obvious fence or other marker (cricket@ida.com.au).

Figure 2.2: A cricket field (http://www.sasportdata.co.za)
The centre of the cricket ball consists of cork and the outer layer is made of leather seamed up by Ifax. A differently coloured ball is used for different playing situations, namely a red ball when playing a day game and for day/night games a white ball is used (Hassan et. al., 2003). The weight of the ball is standardised between 156 and 163 grams for senior cricket and has a circumference of between 224 and 229 mm. (Hassan et. al., 2003; cricket@ida.com.au).

Typical bowling speeds are 130-140 km/h for a fast bowler, 100-130 km/h for a medium pace bowler, and 70-90 km/h for a spin bowler (cricket@ida.com.au). Cricket players have to throw the ball much further compared to netball players. Netball players have a series of shorter passes. Cricket players need more momentum and more power, because the ball travels at a much faster speed and over a much further distance. One could then expect that the cricket players would generate more power through the kinetic chain, with the assistance of a strong core to transfer the energy. Relatively greater internal rotator strength could be expected from netball players because, when compared to cricket players, they mainly use shoulder rotation in their throwing action over a shorter distance.

D. FUNCTIONAL ANATOMY

It is important to have an understanding of the functional anatomy of the shoulder complex to be able to assess the physical factors from within and around this complex that might affect distance throwing in the overhead motion.

In the shoulder joint, stability of the joint is sacrificed for mobility (Thompson & Floyd, 1998). The bones constituting the shoulder joint are the scapula, the clavicle and the humerus, which serve as attachments for the muscles of the shoulder (Ciullo, 1996; Thompson, 1998). Joints, ligaments, capsules and intra-articular extensions interconnect the bones, which allow mobility, but also provide a significant amount of stability (Ciullo, 1996). The bony joint consists of the glenoid, acromion, and humeral head, while the soft tissues include the glenoid labrum, the glenohumeral
ligaments and the cora-acromial ligaments as well as the muscles of the rotator cuff, the long head of the biceps, and the scapulothoracic muscles (Tennent, 2003).

The scapula has various functions in the shoulder joint. Firstly, it is a stable part of the glenohumeral articulations. Secondly, the scapula is retracted and protracted along the thoracic wall, adjusting for movement taking place in the arm. Thirdly, it elevates the acromion in the throwing and serving motion. Fourthly, it is a base for muscle attachment, and finally it functions as a link in the proximal-to-distal sequencing of velocity, energy and forces that allow the most appropriate shoulder function (Elliot, 1995; Kibler, 1995).

**The four joints of the shoulder complex**

All these shoulder joints, but the scapulothoracic joint, are synovial joints. The scapulothoracic joint falls outside any category of any traditional classification.

**Sternoclavicular joint**

The sternoclavicular joint is classified as a multiaxial joint. This acts as the skeletal attachment, which attaches the upper extremity to the axial skeleton (Ciullo, 1996; Thompson, 1998). The sternoclavicular joint, along with the acromioclavicular joint, enables the glenohumeral joint to be moved through a full 180° of abduction. There is a disk between the two bony surfaces and the capsule is thicker on the anterior side than on the posterior side. The disc that separates the bone surfaces adds significant strength to the joint, and in this way prevents medial displacement of the clavicle (Magee, 2002).

The stability in this joint is provided almost entirely by the ligamentous structures because of the rounded proximal clavicle that is attached to a very shallow sternomanubrial fossa (Ciullo, 1996; Thompson, 1998). These include the anterior and posterior sternoclavicular ligaments, which act in supporting the joint anteriorly and
posteriorly. The interclavicular ligament, as well as the costoclavicular ligament running from the clavicle to the first rib and the costal cartilage, are the main ligaments responsible for maintaining the integrity of the sternoclavicular joint (Magee, 2002).

The closed pack position of the sternoclavicular joint is in full or maximum rotation of the clavicle, which occurs when the upper arms are fully elevated (Magee, 2002). The intra-articular movement that could take place in this joint because of the free disk arrangement, allows for $30^\circ$ of elevation, $30^\circ$ anterior-posterior flexion and approximately $45^\circ$ of rotation along the functional axis (Ciullo, 1996). With protraction it moves $15^\circ$ anteriorly and with retraction it moves $15^\circ$ posteriorly. It can move $45^\circ$ superiorly when elevation takes place and $5^\circ$ inferiorly with depression. Anteriorly the anterior sternoclavicular ligaments support the joint, which provide stability against superior displacement (Thompson & Floyd, 1994).

The nerves that innervate the joint are the branches of the anterior supraclavicular nerve and the nerve to the subclavius (Magee, 2002).

Acromioclavicular joint

The acromioclavicular joint is the attachment of the clavicle to the scapula. This generally has an open front V-shaped configuration, with the closest contact being directly posterior. A horseshoe-shaped disk with a thin covering between the two ends and thicker anterior cartilage fits in the V-shaped joint. The stability anteriorly and posteriorly clinically appears to be controlled by the capsular ligaments that are anterior and posterior of the joint.

Because of the V-shaped configuration of the joint, it allows anterior compression as the arm is elevated and horizontally flexed. This then allows smoother scapulothoracic rotation on the ribs, especially in the initial $20^\circ$ to $40^\circ$ of elevation were the scapulothoracic slide is the greatest (Ciullio, 1996).
The acromioclavicular joint is a synovial joint that increases the range of motion of the humerus in the glenoid. The bones involved in this joint are the acromion process of the scapula and the lateral end of the clavicle. The joint has three degrees of freedom. A fibrous capsule surrounds the joint, and an articular disc may be found in the joint. The joint depends on ligaments that surround the joint and these ligaments are commonly the first ligaments to be injured when stresses are placed on the joint.

In the closed pack position of the joint, the arm is abducted to 90°. The branches of the suprascapularis and lateral pectoral nerves innervate the joint (Magee, 2002). The joint is an arthrodial joint and has a 20 to 30° total gliding and rotational motion that accompany other shoulder girdle and shoulder joint motions (Thompson & Floyd, 1998). The conoid and trapezoid coracoclavicular ligaments primarily control the superior and inferior stability (Ciullo, 1996).

There are three groups of muscles that attach to the scapula. The first group is responsible for stabilisation and rotation of the scapula and is composed of the trapezius, rhomboids, levator scapulae and the serratus anterior muscles. The second group includes the extrinsic muscles of the shoulder joint, which are the deltoid, biceps and the triceps muscles. The third group is the intrinsic muscles of the rotator cuff, and consists of the subscapularis, the supraspinatus, the infraspinatus and the teres minor muscles (Kibler, 1998).

When the scapula is tilted forward it causes forward angling in the glenoid and its attached capsuloligamentous complex. This altered position is then likely to contribute to stability and alter the orientation of the inferior glenohumeral ligament (Weiser et al., 1999).

**Glenohumeral joint**

The glenohumeral joint, which is most commonly known as the shoulder joint, is a multi-axial ball and socket joint and classified as synovial joint. In this joint the muscles and ligaments – rather than the bony structures – play a major role in its
stabilisation, support and integrity (Magee, 2002). The capsular ligaments, articular components, negative intra-articular pressure, and the glenoid labrum assist the shoulder in its static stability (Peterson & Renström, 2001). If the glenohumeral joint is unstable, an increase in humeral head translation could lead to shearing and injury. The injuries that are commonly encountered in athletes using overhead throwing actions or workers with overhead actions relate to the glenoid labrum, rotator cuff impingement, tendonitis, and labral pathology (Malanga, 1999).

The joint fluid provides a hydraulic fit that helps in maintaining the integrity of the joint. A small depression in the anterior capsule above the leading edge of the subscapularis muscle could contain extra fluid to help regulate the hydraulic mechanism. This causes an overall negative pressure to keep the humerus stable in the glenoid (Ciullo, 1996).

When the glenohumeral joint is in its resting position, it is at 55° of abduction and 30° of horizontal adduction, which is the close packed position of the joint. When the arm is relaxed, the humerus sits in the centre of the glenoid cavity. When the rotator cuff contracts, it causes an anterior, posterior, inferior or superior translation, or a combination of these movements. The movement that the rotator cuff causes is very small, but essential, because without this, full range of motion would not be possible. When in a resting position, the glenoid is tilted superiorly 5° and has a 7° slight medial rotation. The angle between the humeral head is slightly medially rotated, 30 to 40° relative to the line joining the epicondyle (Ciullo, 1996).

The primary ligaments of the glenohumeral joint consist of the inferior, superior, and the middle glenohumeral ligaments. These ligaments play an important role in the stability of the shoulder (Warner, 1993). The role of the superior glenohumeral ligaments is to limit inferior translation in adduction. It also acts as a restraint to anterior translation and to lateral rotation up to 45° of abduction. When intact, this ligament helps to prevent inferior subluxation of the shoulder. Along with the posterior capsule this ligament helps to provide stability against anterior and particularly posterior subluxation (Magee, 2002).
The role of the middle glenohumeral ligament, which is absent in 30% of the population, is to act in limiting the lateral rotation between 45° and 90° of abduction (Thompson, 1998; Magee, 2002). When this ligament is present, it functions to limit external rotation, preventing displacement as the shoulder swings out of joint around the axis. This restriction is also provided by the superior glenohumeral ligaments and the long head of the bicep tendon.

The role of the inferior glenohumeral ligament is the most important of the three ligaments. It has an anterior and a posterior band with a thin “pouch” between the two, acting as a hammock. It acts in supporting the humeral head when above 90° of abduction, limiting the inferior translation. The anterior band tightens with external rotation, and the posterior band tightens with internal rotation (Davies & Dickhoffman, 1993).

The coracohumeral ligament is found between the anterior border of the supraspinatus tendon and the superior border of the subscapularis tendon. It primarily limits inferior translation, and helps limit lateral rotation below 60° of abduction (Magee, 2002). The primary role of the coracohumeral ligament is to limit the external rotation below 60° of abduction (Peat, 1986). This ligament forms an arc over the humeral head and acts as an obstruction to prevent superior translation.

The transverse humeral ligament forms a roof over the bicipital groove to hold the long head of the bicep tendon within the groove. Because of the capsular pattern of the glenohumeral joint, external rotation is the most limited movement, followed by abduction, and internal rotation. On the glenohumeral capsule there are approximately three anterior thickenings and one less substantial posterior thickening that acts as a structural band to stabilise the joint (Ciullo, 1996).

Because of the minimal bony containment of the humeral head in the glenoid cavity, a wide range of shoulder movements are possible (Paxinos et al., 2001). The posterior cord of the brachial plexus and the suprascapular, axillary and lateral pectoral nerve innervate the joint (Thompson, 1998).
E. MUSCLES INVOLVED IN THE SHOULDER COMPLEX

The rotator cuff

The rotator cuff’s primary function is to aid in the stabilisation of the glenohumeral joint by compressing the humeral head in the glenoid fossa, but it also assists with some shoulder motion (Malanga et al., 1999). These muscles are biomechanically considered as the “compressor cuff” of the humerus head into the socket. Because the rotator cuff is responsible to act as movers and stabilisers, these muscles are more prone to injury (Mcleod & Andrews, 1986). According to Hinton (1988) the rotator cuff has various functions in the shoulder. Firstly, it acts as a dynamic humeral rotator; secondly, a humeral head depressor, and thirdly, an active/passive restraint to gross joint instability. It also serves to protect the labrum and articular cartilage surfaces, because of the finely tuned actions that help control subtle joint translations and contact areas within the glenohumeral joint.

A study by Jenp et al. (1996) examined the function of eight shoulder muscles, performing isometric internal and external rotation activities of the shoulder joint in different positions, to assess which position is optimal for generating maximal EMG-activity of the rotator muscles. Subjects were ten healthy men and ten women with no previous history of surgical procedures, trauma, arthritis, diagnosed impingement, or dislocation or fracture of any structure of the shoulder complex. The ages of the subjects ranged from 23 to 36 (30.3 ± 4.6) and all subjects were right-handed. The positions the subjects were tested in was elevation of the arm to 15° in the frontal plane for clearance in external rotation (dependant position); elevation of the arm at 90° in the frontal plane (frontal position); starting from frontal position and forward flexing the arm to a plane parallel to the scapula (scapular plane at 90°); 45° elevation of the arm in the scapular plane; and starting from the frontal position and forward flexing the arm to the sagittal plane (sagittal position). The two main functions of the rotator cuff on the glenohumeral joint were shown to be stabilisation of the humeral head in the glenoid fossa under static and dynamic conditions, and activation of the muscle complex for joint movement (Inman et al., 1944; Perry, 1983).
The rotator cuff muscles fire maximally to stabilise the shoulder in the midrange position as the ligaments and capsule become more lax (Jenp et al., 1996). It was found that the rotator cuff muscles, along with the biceps muscle, stabilise the shoulder by compressing the humeral head against the glenoid. The deltoid muscle, which is almost as close to the humeral head as the rotator cuff muscles, is the largest muscle around the shoulder, and has similar or even greater stabilising functions (Kido et al., 2003).

The extrinsic muscles of the rotator cuff (deltoid, biceps and triceps) attach along the lateral aspect of the scapula. Their main function is to perform the gross movements of the glenohumeral joint (Saha, 1971). The intrinsic muscles of the rotator cuff are attached all along the surface of the scapula. These muscles are aligned so that the line of pull is the most efficient for activity, working concentrically or eccentrically in a straight line when the arm is at 70° and 100° of abduction (Poppen & Walker, 1976).

**Infraspinatus**

Infraspinatus originates on the medial aspect of the infraspinatus fossa of the scapula, overlying dense fascia and the spine of the scapula, just below the spine of the scapula, and inserts posteriorly on the greater tubercle of the humerus (McDonough, 1994; Thompson, 1998). On the superficial surface it is bounded by a vascular fascial space on the deep surface of the deltoid (Morrey et al., 1998). The insertion is shared with the supraspinatus anterior superiorly and teres minor inferiorly at the greater tuberosity (McDonough, 1994; Morrey et al., 1998; Thompson, 1998).

The infraspinatus causes external rotation, horizontal abduction, extension of the glenohumeral joint, as well as stabilisation of the humeral head in the glenoid fossa. It helps to hold the humeral head in the glenoid cavity of the scapula (McDonough, 1994; Thompson, 1998; Oatis, 2004). The muscle is innervated by the suprascapular nerve of C5 and 6 (McDonough, 1994; Thompson, 1998).
**Teres minor**

The origin of the teres minor is on the upper and middle aspects of the middle portion of the lateral border of the scapula and the dense fascia of the infraspinatus (McDonough, 1994; Morrey et al., 1998; Thompson, 1998). The insertion of the teres minor is on the inferior facet on the greater tubercle of the humerus (McDonough, 1994; Morrey et al., 1998; Thompson, 1998). The teres minor laterally rotates the shoulder, adducts and extends the shoulder, and helps to hold the humeral head in the glenoid cavity of the scapula (McDonough, 1994; Thompson, 1998; Oatis, 2004). The axillary nerve of C5 and C6 innervates the teres minor (McDonough, 1994; Thompson, 1998).

**Subscapularis**

The anterior portion of the rotator cuff consists of the subscapularis (Warner et al., 1990). The origin of the subscapularis is from the subscapularis fossa, which covers most of the anterior surface of the scapula (McDonough, 1994; Morrey et al., 1998; Thompson, 1998). It inserts through a collagen-rich tendon into the lesser tuberosity of the humerus (McDonough, 1994; Morrey et al., 1998; Thompson, 1998).

The subscapularis is responsible for the medial rotation of the arm, adduction of the shoulder, horizontal adduction of the shoulder and stabilisation of the glenohumeral joint. It also helps in holding the humeral head in the glenoid cavity (McDonough, 1994; Thompson, 1998; Oatis, 2004).

Innervation is usually supplied by two sources, namely the upper subscapular nerve (C5) which supplies the upper portion, and the lower subscapula nerve (C5, C6, C7) supplying the lower portion of the subscapularis (McDonough, 1994; Thompson, 1998).


**Supraspinatus**

The supraspinatus is the most often-injured rotator cuff muscle. Acute severe injuries may occur with trauma to the shoulder. Injury or weakness in the supraspinatus may be detected when the athlete attempts to substitute the scapula elevators and upward rotators to obtain humeral abduction (Thompson, 1998). The muscle originates from the medial two-thirds of the supraspinatus fossa of the scapula and the overlying fascia (McDonough, 1994; Thompson, 1998). The supraspinatus inserts on the superior facet on the greater tubercle of the humerus. Its tendinous insertion combines with the infraspinatus posteriorly and the coracohumeral ligament anteriorly (McDonough, 1994; Thompson, 1998).

The supraspinatus initiates and assists the deltoid in abduction of the arm, lateral rotation of the shoulder, and stabilisation of the glenohumeral joint (McDonough, 1994; Oatis, 2004). Innervations of the supraspinatus are supplied by the suprascapular nerve, C4, C5, and C6 (McDonough, 1994; Thompson, 1998). Rotation is not considered the major function of the supraspinatus muscle (Jenp et al, 1996).

The supraspinatus muscle holds the head of the humerus in the glenoid fossa. In throwing movements, it provides important dynamic stability by maintaining the proper relationship between the humeral head and the glenoid fossa. In the cocking phase of throwing, there is a tendency for the humeral head to subluxate anteriorly. In the follow-through phase, the humeral head tends to move posteriorly (Thompson, 1998). The peak activity of the supraspinatus and other rotator cuff muscles occurs in the late cocking phase when the arm is already abducted and is most susceptible to subluxation. The supraspinatus contributes to stability by drawing the humeral head towards the glenoid fossa (Peterson & Renström, 2001).
Serratus anterior

The serratus anterior has been described as the main mover of the scapula, because of the position of its insertion (Ludewig et al., 2004). The primary muscle responsible for maintenance of normal scapulohumeral rhythm is the serratus anterior (Dvir & Berme, 1978). When there is a lack of strength or endurance in the serratus anterior, it allows the scapula to rest in a downwardly rotated position, and the inferior border then becomes more prominent, which is called a winged scapula (Decker et al., 1999). When the serratus anterior muscle becomes fatigued, it reduces the scapular rotation and protraction, which then allows the humeral head to translate anteriorly and superiorly. This unwanted movement can lead to secondary impingement or rotator cuff tears (Decker et al., 1999).

The serratus anterior originates from the external surface of the lateral parts of the first eight ribs and inserts along the medial aspect of the scapula (Paine & Voight, 1993; McDonough, 1994). The upper portion of the serratus anterior insertion is along the medial border of the scapula. The lower portion inserts into the inferior angle of the scapula, and the anterior surface of the medial border of the scapula (Paine & Voight, 1993; McDonough, 1994). This insertion results in a moment arm that is larger than the moment arms of the other muscles that attach to the scapula and thorax, which contributes to the production of the upward rotation and posterior tilting of the scapula (Dvir & Berme, 1978; Weiser et al., 1999; Oatis, 2004). As a result of the multiple attachment sites of the serratus anterior, this muscle plays a primary role in stabilising the scapula when the arm is elevated (Paine & Voight, 1993).

The long thoracic nerve innervates the serratus anterior, which arises from the ventral rami of the fifth and seventh cranial nerves also C5, C6, C7 (Paine & Voight, 1993; McDonough, 1994).
Rhomboids

The rhomboid minor originates from the spinous process of the seventh cervical and the first thoracic vertebrae and inserts into the medial border of the scapula near the scapular spine. The origin of the rhomboid major is at the second through to the fifth thoracic vertebrae and inserts into the medial border of the scapula just below the insertion of the minor (Paine & Voight, 1993; McDonough, 1994). Both the major and the minor rhomboids adduct the scapula (McDonough, 1994).

The rhomboids, both the minor and the major, act to stabilise the medial border of the scapula, and are very active in the adduction or retraction of the scapula. It is thus important that the athlete who uses overhead throwing actions, must be able to protract the scapula effectively (Kibler, 1991). During the acceleration phase of pitching, a high level of rhomboid activity was found. This suggests that the rhomboids are contracting eccentrically to provide stabilisation to the medial border of the scapula during acceleration. There is also high EMG activity during the follow-through phase of the throw, because of the eccentric muscle contraction to decelerate the energy released during acceleration (DiGiovine et al., 1992). It is therefore very important for throwing athletes and athletes using overhead throwing actions to strengthen their rhomboids (Paine & Voight, 1993).

The dorsal scapular nerve, C4, C5, innervates both the rhomboid major and minor (McDonough, 1994). If the rhomboids were weak, the scapula would not be able to achieve full retraction. The inability to achieve full retraction of the scapula during throwing or overhead motion could lead to increased stress on the anterior structures of the shoulder (Paine & Voight, 1993).

Upper trapezius and levator scapula

The origin of the upper trapezius is on the superior nuchal line, the external occipital protuberance of the skull, and the seventh cervical vertebra. The levator scapula
originates on the posterior tubercles of the transverse processes of the cervical vertebrae from one to four (Paine & Voight, 1993). The upper trapezius fibres lie downward to insert into the distal third of the scapula. The fibres of the levator scapula insert along the medial border of the scapula at the level of the scapular spine (Paine & Voight, 1993).

The upper trapezius assists in the upward rotation of the scapula. The upper trapezius and the levator scapula are strongly involved in elevation of the scapula, adduction of the scapula, and the upward rotation of the scapula (Paine & Voight, 1993; Weiser et al., 1999; Oatis, 2004). When the scapula is held in its proper position by these muscles, it also acts in optimising the stability at the glenohumeral joint. When the scapula gets protracted, it abducts from the midline, and because of the conformity on the thoracic case, it is caused to tilt forward (Weiser et al., 1999).

The innervation of the upper trapezius is provided by the spinal accessory nerve. The cervical plexus provides innervations to the levator scapula, with contributions also from the dorsal scapular nerve (Paine & Voight, 1993).

**Pectoralis minor**

The origin of the pectoralis minor is from the axial skeleton 3rd to 5th ribs near the costal cartilages (Paine & Voight, 1993; McDonough, 1994). It inserts into the medial aspect of the superior surface of the coracoid process on the scapula (Paine & Voight, 1993; McDonough, 1994).

The pectoralis minor performs abduction, depression, downward rotation, and upward tilt of the scapula (Paine & Voight, 1993). Forward rotation of scapula is aided by contraction of the lower fibres of the serratus anterior, and the trapezius and levator scapulae (Kent, 1971).

The medial-lateral pectoralis nerves, C8 and T1, innervate the pectoralis minor (Paine & Voight, 1993; McDonough, 1994).
Deltoid

The deltoid muscle is a triangular bulky muscle that constitutes approximately 20% of the shoulder’s musculature. It has a wide origin with a narrow insertion. This muscle can be divided into three portions, which all originate from different points. Most research on the deltoid muscles has focused on its moving function, rather than on its stabilising function (Kido et al., 2003).

The origin of the deltoid is on the lateral third of clavicle, on the lateral margin and the superior surface of the acromion, and on the lower edge of the crest of the scapular spine (McDonough, 1994; Kido et al, 2003). It covers the proximal portion of the humerus and then proceeds into a thick tendinous insertion at the lateral surface of the humeral shaft (Kido et al., 2003). This muscle inserts on the deltoid tuberosity of the humerus (McDonough, 1994).

The deltoid muscle has the largest momentum force on the arm and is seen as the primary elevator of the arm. The movements caused are abduction, adduction, flexion, medial rotation, and extension of the shoulder joint (McDonough, 1994). Actions of the anterior deltoid have been reported to be flexion, medial rotation, horizontal adduction, and shoulder abduction (Oatis, 2004). When the arm is in abduction and external rotation, the deltoid acts as an anterior stabiliser of the shoulder. Each portion contributes equally to anterior stability under constant loading conditions. When the arm is externally rotated, the deltoid muscle’s insertion is located more posteriorly than with the arm in a neutral position (Kido et al., 2003).

The main mechanism for stabilisation of the shoulder by the deltoid seems to be compression of the humeral head, rather than the passive tension caused by the bulk effect. The moderate contraction of the deltoid muscle occurs during the late cocking and acceleration phases, which may contribute to anterior stability of the shoulder. The function of the deltoid is to act as an anterior stabiliser, and it becomes more
prominent when the shoulder becomes unstable (Kido et al., 2003). The deltoid muscle is innervated by the axillary nerve, C5, and C6 (McDonough, 1994).

**Latissimus dorsi**

The origin of the latissimus dorsi muscle is on the spines of T7 – T12 thoracolumbar fascia, the iliac crest, and the ninth to twelfth rib (McDonough, 1994). The latissimus dorsi muscle inserts at the floor of the bicipital groove of the humerus (McDonough, 1994).

The latissimus dorsi extends, adducts and medially rotates the humerus. During climbing actions it aids in lifting the body towards the arms (Oatis, 2004).

The thoracodorsal nerve as well as, C6, C7, and C8 innervate the latissimus dorsi muscle (McDonough, 1994).

### F. SCAPULAR MOVEMENT

Because of the conformity of the scapula to the convex thoracic cage, a lateral slide and a forward tilt takes place when the scapula is protracted. Thus, when the latter action takes place, the laterally located glenoid angles to a more anterior position. With this change taking place, the glenohumeral translation is decreased. Also with the scapula protraction, the tautness in the anterior band of the glenohumeral ligament increases. This shows that a normal scapulothoracic motion is important for pain-free shoulders (Weiser et al., 1999).

The main reason stated for scapular protraction is to minimise the involvement of the anterior deltoid, to thus prevent overload of this muscle (Bourque & Armand, 1998).
The importance of the scapula for movement

Normal scapular function is important for a thrower. Normal scapular function provides a stable base for the rapid rotating humerus, and it maintains the glenoid in the optimal position for the movement of the humeral head, reducing the stress on the shoulder capsule. There are many throwers with winged scapula or an increase in lateral position of the scapula. When the scapula is in the lateral position, it may predispose the shoulder to anterior instability (Altchek & Levinson, 2000).

Because of the ball and socket design of the shoulder joint, it allows freedom of movement, but consequently the shoulder is mobile and unstable. The control and the stability of the scapula play a significant role in the effective functioning of the shoulder of the throwing athlete (Davies et al., 2000). This is because the scapula serves as an important anchor for the muscles of the shoulder (Chandler, 2000).

During the follow-through action in throwing, the amount of scapula protraction taking place is equivalent to the amount of acromion and scapular movement that takes place anteriorly and inferiorly around the thorax. The joint position during the follow-through movement, as well as the acceleration phase of the throw, pose an increased risk of rotator cuff impingement in the throwing arm. The stabilisation of the scapula is thus important in the prevention of injuries (Kibler, 1998).

G. THROWING

Overall performance objective

The throwing motion is characterised by the body segments moving in a specific sequential order. This motion then results in the production of a summated velocity at the end of the chain of the distal segments used. The overall performance objective of
the throw in netball and cricket is being stated as throwing to a teammate where the speed of the ball will enhance the success of delivery of the ball (Kreighbaum & Barthels, 1996).

The efficiency of the force passed onto the ball is judged in terms of the speed, distance, and direction of the ball after its release. The speed and distance of the ball that is thrown is directly related to the magnitude of the force used in throwing, and to the speed of the hand at the moment of ball release. The speed that the hand is able to achieve depends on the distance through which the hand moves in the preparatory part of the throw, and the sum of the angular velocities of the contributing body segments. Therefore, the longer the back swing of the preparatory phase, the greater the distance that could be added by means of rotating the body, shifting the weight, and perhaps even taking a step, the greater the accelerating. The joint actions in the shoulder, elbow, wrist and fingers contribute to approximately 50% of the ball speed. The technique of a baseball pitcher is designed to allow the maximum time and distance over which to accelerate the ball before its release. If the ground reaction force is to be maximal, the surface against which the thrower pushes has to be firm with optimum friction to prevent sliding of the foot on the ground surface. If the distance that the ball is travelling is a major objective of the throw, the angle with which the ball is projected, and the effects of the gravitational force and air resistance should also be taken into account (Luttgens & Hamilton, 1997).

**General stages of the throwing action**

It is important to understand what movements take place in the shoulder during a throw. This is a complex interaction of many muscles in the body. In the throw, neuromuscular timing of contractions occur through specific coordinated links for concentric and eccentric muscle actions. The sequence of motions causes the transfer of force from the lower extremities and trunk to the throwing arm, and through the shoulder and elbow, and eventually to the ball at release. The shoulder and elbow
joints should be able to control and accelerate the ball, and also endure the forces that are produced after the release of the ball. The forces and torques generated in the upper extremity often reach levels that can affect the integrity of the structures that are responsible for the stabilisation of the shoulder complex (Reinold et al, 2000).

The throwing action may be divided into three distinct phases, namely the winding-up phase, the cocking phase, and the follow-through phase. Sound technique and a well-adjusted neuromuscular system is needed for a well-coordinated, powerful throw (Luttgens & Hamilton, 1997).

1. Winding-up phase

In the winding-up phase, which is the first stage of the throwing cycle, the muscles initially fire are at low intensity. When the shoulder gets into full elevation, more activity is seen. No consistent pattern of muscle activation was found in this stage of the throwing motion (Jobe, et al, 1983). In the winding-up phase, the athlete assumes a good starting position so that momentum can be generated to help in the acceleration of the ball (Reinold, et al, 2000). Muscles contract more forcefully when they are first put into a stretched position, without being overstretched. This stretch-shortening principle is suggested as reason for the winding-up phase or preliminary movements before the ball is thrown (Luttgens & Hamilton, 1997).

The over-arm throwing pattern is characterised by the rotation of the shoulder joint, where the abducted arm rotates externally. This external rotation implies a stretched position of the muscles for a more forceful contraction (Luttgens & Hamilton, 1997). This winding-up phase through to the cocking phase, where the shoulder reaches maximal external rotation, covers about 80% of the time involved in the pitching or throwing motion (Duba, 1985).
2. Cocking phase

In the arm-cocking phase the athlete reaches a maximum external rotation of the shoulder joint (Reinold, et al., 2000). In the forward phase, the abducted arm is rotated internally, while a degree of elbow extension, wrist flexion and spinal rotation also takes place. There is also some movement in the pelvis at the hip joint of the opposite limb, which results in medial rotation of the thigh (Luttgens & Hamilton, 1997).

In the cocking phase, significant muscle activation patterns are indicated. The shoulder becomes elevated to 90° and movement progressively takes place from flexion to extension in a horizontal plane. Trunk rotation also starts, but minimal rotation takes place at the shoulder until just prior to the front foot making contact with the ground. The anterior, middle and posterior deltoids all experience peak activity when the arm is held at 90° of elevation. By the end of this phase, the rotator cuff muscles (supraspinatus, infraspinatus and the teres minor) all begin to fire, with the supraspinatus showing the most powerful activity. After the foot makes contact with the ground, the arm completes its rotation to maximum external rotation, and the trunk begins its forward rotation. The rotator cuff muscles initially continue to fire, but then become inactive. Muscle activity form the subscapularis shown, most probably to decelerate the shoulder’s external rotation. The final shoulder movement in the cocking is flexion to a neutral position in a horizontal plane at 90° of elevation. At this stage, the only muscle with significant activity is the subscapularis. In the cocking phase, there are significant muscle activation patterns, namely deltoid activity, followed by the rotator cuff muscle activity, and finally the subscapularis (Jobe, et al., 1983).

A very short acceleration phase occurs, lasting less than 1/10 of a second. The shoulder capsule gets wound tight in the cocking phase, and in this phase it is released like a coiled spring. The trunk flexion forward initiates movement and the shoulder rotates inwardly and towards horizontal flexion. Even though there is acceleration forward in space, there is a notable lack in muscle activity of the shoulder muscles in this short acceleration phase (Jobe et al., 1983).
In EMG studies it was shown that the rotator cuff musculature, biceps and also the larger trunk musculature remain relatively inactive during the acceleration phase. The rotator cuff muscles act as dynamic stabilisers, providing direct compression of the humeral head in the glenoid fossa so that they can help limit any abnormal translation of the humerus (Matsen, *et al.*, 1991).

The lack of muscle activity in the acceleration phase is remarkable. This is an indication that the prime function of the rotator cuff is to stabilise, rather than to activate, the glenohumeral joint. The humeral acceleration emanates from the trunk rotation, which forces the arm forward, transmitting through a wound-up capsule, and also from the extrinsic shoulder musculature. The exact contribution of each activity is unknown (Jobe *et al.*, 1983).

### 3. Follow-through phase

In the third or follow-through phase, the shoulder continues with internal rotation as well as horizontal flexion. This is the phase where all the muscles are the most active. The subscapularis is responsible for the internal rotation of the shoulder, and the remaining rotator cuff and deltoid muscles are decelerating the arm in space (Jobe *et al.*, 1983). A typical internal rotation velocity during a baseball pitch is over 7,000°/second. It is thus clear that the athlete puts his shoulder joint under tremendous stress, especially during the deceleration of the arm (Zheng, 1999).

Several research studies on the throwing action prove to be quite revealing. For instance, the muscle patterns when merely throwing an easy underarm throw are similar to the muscle actions when throwing with a wind-up action. Thus throwing in different ways or in different sports could well elicit the same or similar muscle actions. All the muscle activities of the anterior, posterior and the middle deltoids seems to be similar, with the peak activity in the early cocking phase, as well as in the follow-through phases. The infraspinatus and the teres minor muscles have similar patterns with peak activity during the early cocking phase, and the follow-through phase. The supraspinatus is usually activated just prior to or together with the
infraspinatus and the teres minor muscles. The peak activity of the subscapularis is at the end of the cocking phase, and in the follow-through phase (Jobe et al, 1983).

Because of the unique characteristics of each sport, there are different movement patterns in each of the actions, and thus the kinematic and kinetic data will be different. Most research has been done on the baseball pitch. There are, however, similarities between overhead motions and the baseball pitch in terms of the amounts of force and torque that are produced, the order in which they are produced, as well as the control of the overhead motion activities (Reinold et al., 2000).

If a throwing athlete involves larger body parts to absorb energy, it reduces the amount of stress that is put on the upper extremity to produce the same amount of power (Altchek & Levinson, 2000). Several authors have identified the sequence from the proximal to distal segments in various sports activities, which include baseball pitching, javelin throwing, other throwing, the tennis serve, the tennis forehand, the forehand stroke in squash, the golf swing, and even kicking a ball (Hirashima et al., 2002).

In a study undertaken by DiGiovine et al. (1992), an explanation of the roles of 29 of the muscles of the shoulder girdle and upper extremities during baseball pitching was given. Hirashima et al. (2002) however stated that no study has yet clarified the exact proximal-to-distal sequential muscle activity in the throwing action.

**Muscles used in throwing**

The body may be seen as a linked chain system, and consequently injuries to the shoulder girdle could originate not only from poor scapular and shoulder stability, but also from poor core stability (King, 2000). Thus, when evaluating the upper quarter, functional stability involves assessment of the shoulder girdle, as well as core stability involving the hip and trunk. The scapula and its attached muscles are the fundamental link between the trunk and shoulder girdle. The kinetic chain, of which the arm is the distal link, begins with the legs, courses through the hip and trunk, and continues
through the upper quarter, which involves the shoulder girdle, glenohumeral joint and the arm with the hand as the terminal link (King, 2000).

Depending on the shoulder position to which each muscle contributes, the subscapularis, pectoralis major, latissimus dorsi and teres major are primarily responsible for internal rotational strength. The infraspinatus and teres minor are responsible for the external rotational strength. When the shoulder is rotated externally, the internal rotators (antagonist) fire eccentrically to decelerate the external rotators, and the external rotators (agonist) fire concentrically. When the shoulder is internally rotated, the external rotators (antagonists) fire eccentrically acting to decelerate the concentrically firing internal rotators (agonists) (Scoville et al., 1997).

The role of the levator scapulae and the upper trapezius is to rotate the scapula upward (Inman, 1944). The levator scapula, rather than the lower fibres of the serratus, is described as the upward force. As the serratus anterior and the upper trapezius provide upward rotation and stabilisation of the scapula, the deltoid is able to act on the humerus. This force couple is very important in the upward rotation of the acromion, away from the humerus in the forward elevation of the shoulder, thereby preventing impingement (Paine & Voight, 1993). The seven agonist muscles that are expected to be activated in sequence is the serratus anterior at the sixth rib, serratus anterior at the eight rib, anterior deltoid, pectoralis major, triceps brachii, pronator teres and the flexor capri ulnaris (Hirashima, et al., 2002).

Of the seven-agonist muscles to be activated, the serratus anterior at the sixth rib is found to be the first muscle to be activated, and shortly after this the serratus anterior at the eighth rib is activated. Just after the scapula protractor becomes activated, the anterior deltoids and the pectoralis major begin their activity. Then the flexor capri ulnaris, pronator teres and the triceps brachii all become activated almost at the same time. The biceps brachii gets activated before the triceps brachii, and stops its activity approximately the same time that the triceps brachii muscle begins to contract, and just before release the biceps brachii are activated. The activation of the abdominal muscles is very gradual. The earliest abdominal muscle to become activated is the left external oblique, which takes place in the stride phase. Its main activity is seen just
before the foot strikes the ground. The reason for the contraction before the lead foot strikes, is to prevent the upper torso from rotating with the pelvis to face the target (Hirashima et al., 2002).

When the torso is rotated leftwards in the direction of the target, the right oblique has its main activity, which is almost simultaneous with the serratus anterior at the eighth rib. This might be an indication that not all the muscles are always activated in sequence from the lower to the upper parts of the body. The main global activity of the rectus abdominis is found to be just before release of the ball. It is interesting that the scapular protractors (which is the serratus anterior), and also the shoulder horizontal flexors (which is the pectoralis major and anterior deltoid), never precede their respective more distal muscles. This raises the possibility that the precedence of the proximal muscles is essential for achieving a high ball speed in a throw. The activation of the left external oblique before the right external oblique prevents the upper torso from rotating together with the pelvis so that the body faces the target, and also stretches the other muscles in the trunk. The right external oblique gets activated almost as the foot strikes, which means that the upper torso rotation leftwards does not become activated until at the moment the left foot touches the ground. The peak activities in the six parts of the rectus abdominis occur just before the point of release. There is also a large angular velocity of the shoulder, elbow and wrist that occurs before the point of release. It is possible that the rectus abdominis has some bearing on the centripetal force required for the circular motion of the upper extremity. This is firstly because the higher the angular velocity, the more necessary it is for the centrifugal point to maintain the circular motion. The second reason might be that, when the point of release is approaching, the distance from the centre of the whole body mass to the ball increases and more centripetal force is required as a result (Hirashima, et al., 2002).

Projectile motions – where the upper extremity is involved and the arm is in an abducted position – are used in various sports activities. There is a chain of actions that causes the transfer of truncal torque to the ultimate projectile velocity, described by Pappas et al. (1985). In some of the reports the accelerating linkage of the trunk to the extremity was associated with an explosive contraction of the internal rotators of
an abducted shoulder (Pappas et al., 1985). This muscle contraction then either powers the motion, or it provides glenohumeral stabilisation when the torque is being transferred (Pappas et al., 1985). Because of the complex nature of these motions, it is difficult to determine the physical factors that ultimately affect the performance of these athletes. In a study done by Pedegana (1982), it was demonstrated that by isolating and testing different upper extremity movements, there was only two factors that statistically correlated with the throwing speed. These were wrist extension, as well as elbow extension. A number of studies have been undertaken to compare throwing athletes with non-throwing athletes in an attempt to identify differences in shoulder rotator strength (Brown et al., 1988). It was found that strength training led to functional gains in several activities (Ellenbecker, et al., 1988). Comparing the dominant arm with the non-dominant arm, there were significant differences in external rotation at $90^\circ$ of abduction. When the arm was in the neutral position, no significant differences were found between the dominant and the non-dominant arm. This suggested that the increase in external rotation with abduction is a specific adaptation, resulting from the throwing mechanism (Brown et al., 1988). There are no known studies where the relationship between flexibility and velocity with which the ball is thrown, were measured.

**Normal biomechanics of the throwing action in netball and cricket**

According to a study by Dillman et al. (1993) on elite baseball players, the speed of the ball when released is estimated to be $6,940^\circ$/sec ($\pm 1080^\circ$/sec). During the cocking phase, the humeral head experiences a force of anterior translation that is equal to about 40% of an athlete’s body weight, and in the follow-through phase, a distraction force of about 80% of body weight is created.

When there is posterior glenohumeral inflexibility, whether it is capsular tightness or muscular tightness, it may cause abnormal biomechanics. This could create a winding-up effect where the glenoid and scapula are pulled in a forward and inferior direction by the moving arm. In the follow-through, the throwing arm is brought to a
horizontally abducted position, which may cause the scapula to place an excessive amount of protraction on the thorax (Kibler, 1998).

Scapulohumeral rhythm is responsible for the positioning of the humerus in the glenoid cavity, and it is critical for the glenohumeral joint to be positioned properly during the throwing motion. When there is a disturbance in the normal scapulohumeral rhythm, it may cause inappropriate positioning of the humeral head relative to the glenoid, which may result in injury (Jobe & Pink, 1993).

Glenohumeral rhythm

Most of the shoulder’s movement occurs in the glenohumeral and in the scapulothoracic joints. The rhythm between the glenohumeral and scapulothoracic joints has been determined as a ratio of 2:1 of glenohumeral to scapulothoracic motion. Thus when there is a 180° of total abduction in the shoulder, 120° of the motion is from the glenohumeral joint and 60° of the motion emanates from the scapulothoracic joint. The early portion of movement takes place in the glenohumeral joint, which represents 4.4 for every degree of scapulothoracic motion. As the shoulder gets to 90° of abduction, the ratio changes to 1.1° of glenohumeral motion for every degree of scapulothoracic motion (Bigliani, et al., 1985). When further glenohumeral abduction occurs, the scapula is rotated about a fixed axis through a arc of approximately 65° by the time full elevation is reached (Poppen & Walker, 1976). The scapula forms the platform for the humeral head articulation and motion, because of the glenoid being the contact point of the humerus (Malanga, et al., 1999).

Deceleration after ball release

After the ball is released, the upper extremity needs to be decelerated, because of the tremendous speed that is generated in the shoulder joint during the throw. The musculature of the posterior cuff is most active in this action, checking humeral internal rotation and horizontal adduction. The muscles that retract the scapula, act to
decelerate the gross shoulder girdle protraction as well as adduction, acting in a complementary manner. It is often found that the muscles responsible for the deceleration of the shoulder girdle are weaker on the dominant side of a pitcher. The explanation for this may be that these muscles have developed a stretch weakness, which could be ascribed to the exaggerated, protracted depressed posture of the shoulder (Kibler et al., 1992). When the athlete throws the ball, the arm is decelerated by the shoulder external rotators and elbow flexors, which are then prone to micro-trauma (Clements et al., 2001).

If the muscles of the scapula are unable to fully retract the scapula on the thorax, it causes a loss of a stable cocking point, and also causes an inability to explode out of a full energy position during the acceleration phase. The lack of full scapula protraction causes an increase in the deceleration forces on the shoulder, and because of the tightness in the glenohumeral capsule, it may cause some tightness, which could lead to abnormalities like impingement as the scapula rotates down and forward (Kibler, 1998).

H. STABILITY

1. Core stability

Core stability is a term that has been used quite often of late. According to King (2000), core stability refers to the functional stability of the trunk. It is a combination of appropriate biomechanical alignment from the pelvis to the shoulder girdle, with well-organised and coordinated neuromuscular recruitment of the trunk. Optimal core function for a rehabilitation programme of the upper and lower extremities occurs when there is a combination of trunk mobility and stability. Core stability is seen as the foundation for movement, and should be addressed before strength-training, conditioning and agility activities (King, 2000). The core may be considered as part of the entire trunk. The top part is the rib cage, the bottom part is the pelvis and the middle part is the soft tissue that surrounds the trunk both anteriorly and posteriorly.
Because the ribcage influences the function of the shoulder girdle, the body works as a linked-chain system. According to King (2000), injuries to the shoulder girdle could emanate not only from poor scapular stability, but also from poor core stability.

The lower third of the trunk, which includes the pelvis and the hips, exerts mechanical influences on the position of the upper third. The lower third is influenced by various factors. These include mechanics of the hip joint, pelvic inclination, and neuromuscular recruitment around the pelvic girdle (King, 2000).

**The relationship between core stability and the shoulder complex**

Several studies emphasise the importance of the lower extremities and trunk in baseball pitching (Kibler, 1991; Flesig et al., 1996; Kibler, 1998). The energy generated in the lower extremities during the throwing action gets transferred to the shoulders, and ultimately to the ball through the kinetic chain. This helps in increasing the energy, because the lower extremities are larger body parts and generate more energy than the shoulder joint. This kinetic chain, and the importance of the transfer of energy, could also be true for the throwing motion that is used during netball and cricket. There have only been a few EMG studies on the role of the trunk muscles during overhead throwing activities (Watkins, et al., 1989). Most of the EMG analysis done has focused on the muscles of the shoulder girdle and upper extremities.

Kibler (1995) demonstrated that of the forces generated in a tennis serve, 54% emanate from the trunk and lower quarter. Core stability of the hip and trunk provides a stable platform for the movement of the shoulder girdle.
Anticipatory function of the core stabilisers

Hodges et al. (1996) assessed abdominal muscle action during shoulder movements. It was found that the transverses abdominal muscle and internal oblique contract as much as $38.9 \text{ m.sec}^{-1}$ before the shoulder muscles are contracted. The deltoid’s average reaction time was $188\text{ m.sec}^{-1}$; the abdominal muscles – except the transverses – followed the deltoid contraction by $9.84 \text{ m.sec}^{-1}$. It was found that persons with lower back pain had no abdominal activation preceding deltoid contraction, which is an indication that they had lost the anticipatory nature of the core stabilisers.

When scrutinising spinal stabilisation, the speed with which the abdominal muscles contract in reaction to a force tending to displace the lumbar spine is important, rather than the strength of these muscles (Norris, 2001). As seen in the study by Norris (2001), the deep abdominal muscles have a more significant stabilising function. Thus it is very important that an athlete should dissociate the deep abdominal muscle function from that of the superficial abdominals (Norris, 2001).

Authors such as Friedli et al. (1984) have described the feed-forward postural reactions before the initiation of limb movement. They demonstrated that the trunk muscles act to limit the reactive body movement towards the moving limb. Before the arm flexes, the erector spinae and the external oblique are contracted, while the rectus abdominis contracts before arm extension.

2. Glenohumeral stability

Shoulder stability plays an important role both in preventing injuries, and also in allowing the athlete to throw with accuracy and power, for distance. The shoulder joint is unique in the sense that it has the greatest mobility of any joint in the body and is most predisposed to dislocation (Morrey et al., 1998). The capsulolabral complex that functions in a static manner could be regarded as the primary stabilisers of the shoulder joint (Warner, 1990). The structures involved with the stabilisation of the joint is the rotator cuff, the tendons of which are partially adherent to the
glenohumeral ligaments, acting to tense these ligaments, as well as acting via their bony attachments to the scapula and humerus (Tzannes, & Murrell, 2002). For shoulder stability, a complex interaction between static and dynamic shoulder constraints is needed. The static constraints refer to the bony ball and socket configuration of the shoulder and the major soft tissues holding these bones together. The dynamic shoulder constraints are the musculotendinous joint, which includes the rotator cuff and biceps tendon (Weiser et al., 1999; Paxinos et al., 2001).

The primary function of the rotator cuff is compression of the humeral head on the glenoid to provide stability to the joint. This is needed so that the deltoid and the latissimus, which are the large movers of the shoulder, can function without significant translation of the glenohumeral joint. “Force couples” may be observed where the muscles work synergistically to carry out a particular movement. For instance, the supraspinatus assists in shoulder abduction by maintaining the humeral head centred on the glenoid, while the middle deltoid acts as a primary mover. Previously it was believed that the supraspinatus “initiates” shoulder abduction and acts in the first 30° of shoulder abduction, but in actual fact the supraspinatus fires to stabilise the glenohumeral joint as the deltoid abducts the arm. The infraspinatus and teres minor assist in the centring of the humeral head during overhead activities, and also assist in the external rotation of the shoulder. The subscapularis also participates in the centring, but also acts as a minor internal rotator with the pectoralis muscles and latissimus dorsi acting as the main internal rotators of the shoulder (Malanga, 1999).

There are various factors influencing the prevention of the superior migration of the humeral head, which includes the shape of the acromion, the coracoacromial ligament, the bicep tendon, the thickness of the supraspinatus, the network of the ligaments originating from the coracoid process, and isometric tensioning of the surrounding joint (Ciullo, 1996).
3. **Scapular stability**

It was demonstrated that weakness of the serratus anterior and trapezius causes changes in the scapulo-humeral rhythm (Scovazzo *et al*., 1991). Weaknesses in the scapular muscles may alter the position and the dynamics of the scapula. When the scapular muscles are weak and unable to support, it does not create a stable base for the glenohumeral rotation to take place. The scapula may cause a lateral slide in such a manner that excessive stress on the anterior structures of the shoulder is caused (Paine & Voight, 1993). If the arm has to work off an unstable base where the scapula stabilizers are not functioning, the mechanical efficiency of the entire motion is decreased (Kibler, 1998).

4. **Dynamic stability**

The term dynamic stability describes the stability in the joint that occurs when forceful movement acts on the joint. Because of the nature of the joint, this stability is very important in dynamic movements of the shoulder joint. The rotator cuff is the key muscle responsible for dynamic stability around the glenohumeral joint (Peterson & Renström, 2001). The dynamic stabilisers include the rotator cuff and the scapular stabilisers, which include the teres major, rhomboids, serratus anterior, and trapezius and the levator scapula. For the dynamic stabilisers to function, an intact neuromuscular system is required (Malanga, 1999).

In repetitive overhead activities where there is poor technique, or muscle fatigue, or inadequate warm-up and conditioning the rotator cuff muscle group – particularly the supraspinatus – dynamic stability in the shoulder joint is lacking (Kido *et al*., 2003). There are four mechanisms that function in dynamic stability of the shoulder. The first mechanism of dynamic stability is the passive tension caused by the bulk of the muscles, which acts in stabilising the joint. The second mechanism is the contraction of the muscles causing relative compression on the articular surface of the joint. Thirdly, the joint motion tightens the passive ligaments. The last mechanism is the
barrier effect of the contracted muscle. An example could be the deltoid muscle which produces a larger compressive force to the glenohumeral joint when the arm is elevated than when the arm is passively at the side (Morrey et al., 1998).

As the arm is elevated, the rotator cuff provides a dynamic compressive force to the glenohumeral joints and maintains the humeral head centred on the glenoid (Bassett, 1988). In the cocking phase the glenohumeral joint goes into an abducted and externally rotated position during which dynamic stability is needed in order to maintain humeral head congruency. The acceleration phase − when internal rotation of the humerus occurs − happens at velocities of 6,100 to 9,000 deg/sec (Dillman, 1993), and is then followed by a period of high intensity eccentric decelerative muscular activity by the posterior rotator cuff muscles, following the release of the ball (Jobe et al., 1983).

5. Instability versus laxity

A muscle imbalance or excessive laxity around the joint − in both adults and adolescents − may compromise joint stability and predispose the joint to injury (Clements et al., 2001). The shoulder is also inherently less stable at 90° of abduction compared to the neutral position (Brown, et al., 1988). Because of the complexity of the shoulder joint and having a large range of motion, it is inherently unstable, relying on the surrounding soft tissue structures for stability (Tennent, 2003).

6. Stabilisers versus Mobilisers

Muscles may be categorised into stabilisers or mobilises, due to the various roles they have to perform in coordinated movement. The stabilisers are more deeply situated, aponeurotic (which is a fibrous sheet like or an expanded tendon, which gives attachment to muscle fibres) and slow twitch in nature, whereas the mobilisers are superficial, fusiform and fast twitch muscles (McDonough, 1994). The stabilisers are more active in endurance activities, compared to the mobilisers being more active in
the power activities. For the stabilisers to be activated, resistance levels of as low as 30 – 40% MVC are needed, compared to the mobilisers that need resistance levels of above 40%. Where the stabilisers are selectively weakened, the mobilisers are preferentially recruited and become shortened and tightened (Norris, 2001).

Considering functional and structural characteristics, the stabilisers, which include the transversus abdominis and the internal obliques, are better equipped for postural holding with an “anti-gravity” function (Norris, 2001). Mobilisers are often referred to as the “task muscles” and are better set up for rapid ballistic movements. The rectus abdominus and lateral fibres of the external oblique could be seen as mobilisers in trunk flexion. The internal oblique and transversus abdominis muscles, which insert at the anterior trunk and are attached to the lumbar spine by the lumbo-dorsal fascia, are seen as strong low back supportive structures (Porterfield, 1985).

Stabilising muscles are divided into two categories. This first group is the primary stabilisers, which include the multifidus and transversus abdominis, which act only to stabilise, and do not create significant joint movement. The second group is the secondary stabilisers, such as the internal obliques, which have an excellent stabilising capacity, but can also move joints (Norris, 2001).

I. ISOKINETIC TESTING

Isokinetic testing has been used in testing and performance enhancement for over 30 years (Davies et al., 2000). The Biodex System 3 machine is designed to perform isokinetic testing, which is only one of the many functions of this machine. Isokinetic testing provides valuable information that may be used in identifying weaknesses, ratios and to quantify strength in muscular function (Davies et al., 2000).
J. RANGE OF MOTION

1. Influence of range of motion (ROM) on shoulder stability

It is difficult to determine the exact range of each movement that takes place in the glenohumeral joint, because of the scapular movements that accompany the glenohumeral movement. The range of motion in the glenohumeral joint is described as: 90-95° of abduction; 0° adduction because it is prevented by the trunk; 75° anterior to the trunk; 40-60° of extension; 90-100° of flexion; 70-90° of internal and external rotation; 45° of horizontal abduction; and 135° of horizontal adduction (Thompson, 1998).

Because baseball throwers expect larger external range of motion than the shoulder is designed for, the shoulder should also be stabilised extremely well (Clements et al. 2001). Because of the complexity of the shoulder joint and its large range of motion, it is inherently unstable and relies on the surrounding soft tissue structures for stability (Tennent, 2003).

Bigliani et al. (1997) undertook a study to determine the range of motion and the laxity of asymptomatic shoulders in throwing athletes who participated at elite levels. It was found that the shoulder laxity that is present in the shoulder may be due to the athletes’ repetitive throwing action. It was also found that there is a pre-existing, inherent glenohumeral laxity, which may play a role when selecting these players who would be able to succeed at high level of competition.

It was confirmed by Clements (2001) that overhead athletes develop an increased external rotation range, because of repetitive throwing, and the large strain put on the shoulder during the throwing motion. Because of this action, the rotator cuff muscles have to be able to stabilise throughout this added or extra range. As found by Reid et al. (1986), those athletes who suffered from recurrent shoulder dislocations were unable to generate significant shoulder rotational torque when the arm was in maximal shoulder external rotation with 90° abduction. This position is similar to that
of the late cocking phase, and thus adequate rotator cuff strength is essential during extreme external rotation to prevent shoulder injury. Because adolescent baseball players may not display the same demands on the rotator cuff as adults do, the former do not demonstrate the same increased shoulder external rotation range as the latter (Clements, et al., 2001).

Stanley et al. (2004) completed a study where 51 female tennis players were tested, measuring the relationship between age, height, mass and various playing parameters (hours of play per week, level of competition, starting age, and whether they started playing tennis before puberty). Due to the involvement in repetitive overhead throwing, it has been found that these athletes displayed an increased retroversion of the humeral head, which is associated with the relatively reduced shoulder internal rotation range of motion and an increased external range of motion. Stanley et al. (2004) reported a much higher total range of motion of internal rotators and external rotators than previously reported for males. According to them the total range of motion was 221° on the dominant arm and 220° on the non-dominant arm.

Most throwers show a significant excessive external rotation and limited internal rotation at 90° of abduction (Brown et al., 1988; Wilk, 1993; Bigliani et al., 1997). Tullos and King (1973) believed that the increase in external rotation helps to improve the efficiency of the internal rotator muscles and thus allows the ball to be delivered with greater velocity.

2. Role of shoulder stability in the throwing motion

According to Luttgens and Hamilton (1997) many athletes are injured during the transition phase from the “cocking to the acceleration” phase, where the stabilisation and deceleration function of the long head of the biceps play an important role. It is, however, important that the shoulder girdle is stabilised while it is being protracted by the eccentric contractions of trapezius and rhomboid muscles (Luttgens & Hamilton, 1997).
When the arm is abducted and externally rotated, the rotator cuff muscles are said to act as stabilisers along with the biceps muscle. These muscles stabilise the shoulder by compressing the humeral head against the glenoid. The deltoid muscle, which is almost as close to the humeral head as the rotator cuff and is the largest muscle bulk around the shoulder, seems to have a similar stabilising effect as the rotator cuff (Kido et al., 2003).

The increase in external rotation in throwing athletes means than the shoulder has a greater external rotation range in which the shoulder has to be stabilised. During the throwing action, the upper limb muscles not only have to produce movement, but also have to stabilise the joints. The muscles should consequently have adequate strength to maintain stability at these joints because of the abnormally large torques when throwing the ball (Clements et al., 2001). Because of the high speed and explosive nature of the throwing action, it is vital that the neuromuscular system provides protection for any compromised static restraints of the glenohumeral joint (Altechek, 2000).

3. **Range of motion in the shoulder**

Values of “normal” range of motion should be approached with caution. Many different ranges of motion have been reported by different authors. Protocols are not always reported accurately, making it difficult to predict a “normal” range of motion (Oatis, 2004). Range of motion for the internal and external rotation could vary considerably. The internal rotation was found to be from $49^\circ \pm 3^\circ$ (found in young adult males) to $80^\circ \pm 67.1^\circ$ which is the “normal” value used by the American Academy of Orthopedic Surgeons. External rotation of the shoulder was found to be $90^\circ$ to $101^\circ \pm 2^\circ$ (found in young females) (Murray, 1985; Boone & Azen, 1979). The clinical range of shoulder girdle motion is $30^\circ$ flexion and $30^\circ$ extension, as well as elevation and depression of the scapula. The range of motion in the shoulder is $180^\circ$ of forward flexion and $60^\circ$ of hyperextension; both taken from the neutral position. The normal horizontal adduction is $130^\circ$, also taken from the neutral position. When
taken from the neutral position, the abduction is $180^\circ$ with the supraspinatus outlet impingement arc from $80^\circ$ to $120^\circ$, and the acromioclavicular arc from $120^\circ$ to $180^\circ$. With the arm at the side, the rotation taken when the lower arm is in the vertical plane, the internal rotation should be $80^\circ$ and the external rotation shoulder should be $60^\circ$. With the forearm in the horizontal plane and the arm in the abducted position, the external rotation should be $50^\circ$ and internal rotation $50^\circ$ (Ciullo, 1996).

The combination of internal and external rotation in $90^\circ$ glenohumeral joint abduction is referred to as total rotational range of motion. This is a measurement of the total arc of rotational range of motion of the glenohumeral joint (Ellenbecker et al., 2002). In a study done involving baseball players it was demonstrated that there is a significant difference in the range of motion of the throwing shoulder when compared to the non-throwing shoulder in the athletes who were involved in an overhead throwing motion. In the dominant shoulder, there was an increase in the external rotation and a decrease in the internal rotation. These changes in range of motion could well be the result of the adaptation to repetitive stress (Ciullo, 1996).

In another study it was demonstrated that there was no difference between the internal and external range of motion between painful and pain-free shoulders. It was also said that any change in the range of motion that occurred, might represent a physiologic adaptation to repetitive stress (Bak, 1997).

**Factors that influence range of motion in the shoulder**

When the overhead athlete is throwing, a large demand is placed on the structures in the shoulder, which results in the posterior shoulder musculature shortening and the posterior capsule being subjected to micro trauma, which results in scar tissue formation that causes a tightening (Stanley, et al., 2004).

The instantaneous centre of rotation is positioned more towards the posterior component when external rotation takes place. This means that if the radius were taken from the instantaneous centre of rotation to the anterior component, it would be
greater than when taken to the posterior component, which is thus the limit of the internal rotation. This means that there is more stretch in the anterior component, which would have to resist more torque generated by the external rotation than the posterior component (Branch, 1995).

Other factors that influence shoulder motion are glenohumeral configuration, soft tissue flexibility, and freely gliding surfaces (Perry, 1983).

Jobe et al. (1989) claimed that repetitive throwing could gradually stretch out the anterior capsuloligamentous structures. The reason for this can be the extreme external rotation that is reached when throwing. According to Dillman (1993), the major motion about the shoulder during throwing is external/internal rotation, and in the external rotation a maximum of 170° of external rotation is reached, thus putting the anterior muscles of the shoulder in a stretched position, which in turn may lead to an increase in the anterior-superior humeral head migration when throwing, which could also give rise to rotator cuff pathology. The dynamic nature of the throwing action can be demonstrated by the fact that from foot contact to ball release the time is 0.145 seconds, and during this interval the ball is accelerated from a speed of 6km/hour to 136 km/hour, thus the were the whole body moves in sequence to produce the throw. Pappas et al. (1985) suggested that the primary factors leading to dominant arm loss of internal rotation in the throwing athlete are the reactive fibrous tissue formation in the posterior capsule, as well as musculotendinous tightness of the posterior rotator cuff.

The shoulder is externally rotated to 160° or more in a 90° abducted position, in the late cocking phase of the baseball player’s throw (Brown, et al., 1988). The increase in external rotation that takes place in an abducted position is the direct result of the throwing mechanism. The dominant arms of baseball players display less horizontal extension. This could be ascribed to the tightening of the pectoral muscles because of the repetitive stresses of throwing and also the non-use of its available range of motion during throwing motion. During the throwing motion and in the late cocking phase the latissimus dorsi and pectoral muscles decelerate the externally rotating shoulder, as well as providing the extrinsic thrust during the acceleration phase. The
pectoralis major also assists the subscapularis in carrying the arm across the chest during the follow-through phase. Hypertrophy of the pectoralis major and latissimus dorsi has been observed in the dominant arm of pitchers (Brown et al., 1988).

An increase in the external rotation range of motion and a significant decrease in glenohumeral joint internal rotation have been documented in patients with glenohumeral joint instability, and also identified in patients with impingement (Warner, 1990). In a study by Kibler et al. (1996) on elite-level tennis player it was found that there was a decrease in the total rotational range of motion with the increase in the years of participating competitively.

A study was undertaken comparing the dominant and non-dominant arms of both baseball players and non-baseball players (Ellenbecker et al., 2002). There was no difference in the humeral retroversion between the extremities in non-baseball players. In the professional baseball pitchers there was a large external rotation and limited internal rotation on the dominant extremity. One of the theories behind this is that it could have been the adaptations that has been caused by osseous adaptations due to the repetitive throwing action during the developmental years of the sports persons in addition to the capsular and musculotendinous factors that are present (Ellenbecker et al., 2002).

In another study by Kibler et al. (1996), it was found that the measured rotational range of motion in elite tennis players progressively lose internal and total rotational range of motion as the players aged, and as the number of years they participated concomitantly increased. It is said that athletes using overhead throwing actions routinely present with 110°-120° of external rotation, and as little as 30° internal rotations, but may have normal total rotational range of motion values when compared to the opposite side (Ellenbecker et al., 2002).
The changes in range of motion in throwing athletes

A study was done on baseball pitchers and position players, comparing their dominant and non-dominant arms. Pitchers’ dominant arms demonstrated 9° more external rotation at 90°, 5° less in shoulder flexion, 15° less internal rotation, 11° less horizontal extension, 6° less elbow extension, 4° less elbow flexion, and 5° less forearm supination comparing the dominant to the non-dominant side. Position players demonstrated 8° more external rotation at 90° abduction, 14° less horizontal extension, and 8° less elbow extension on the dominant side compared to the non-dominant side (Brown et al., 1988).

In this same study by Brown et al. (1988) while comparing the dominant arm to the non-dominant arm of professional baseball pitchers. With external rotation they found a significant greater external rotation in the dominant arm (141° vs. 132°). There was a significant decrease in internal rotation in the dominant arm (83° vs. 98°). Total rotational range of motion was not measured, but when summing the measurements it was found that the dominant total range of motion was 224° vs. the non-dominant of 230°. There was no reference that the glenohumeral joint was isolated and thus the possibility of scapulothoracic motion could be added to the measurements of internal and external rotation at 90° of glenohumeral abduction (Ellenbecker et al., 2002).

Comparing dominant arm to the non-dominant arm, it was found that athletes using overhead throwing actions showed evidence of increased external rotational range of motion at the expense of decreases in internal rotational range of motion in their dominant arm. This is an associated anterior instability (Kibler et al., 1996). These limitations in internal rotational range of motion are thought to be due to posterior capsular or cuff tightness (Pappas et al., 1985). In the study by Bigliani et al. (1997) professional baseball pitchers were measured at 90° of glenohumeral joint abduction. Dominant arm external rotation was significantly greater (118°) than the non-dominant arm (103°).
In studies on highly skilled tennis players, it was reported that there was a reduction in the internal glenohumeral range of motion of the dominant arm (Chandler et al., 1990), and an increase in the external range of motion, when compared to the non-dominant side (Kibler et al., 1996). Posterior capsular tightness and rotator cuff muscle imbalance are the factors postulated to have caused this imbalance. Osseous adaptations that take place in the prepubescent years is another possible factor contributing to the alterations in range of motion. It has been found that the athletes using overhead throwing actions involved in repetitive overhead throwing have an increased retroversion of the humeral head, which is associated with reduced internal rotation and an increased external rotation.

In studies done on tennis players (Chandler et al., 1990; Ellenbecker, 1992) it was found that there was a significant decrease in the internal range of motion and a significant increase in external range of motion when comparing the dominant to the non-dominant arm. It was also found that internal/external ratios in these athletes are greater in the men than in the females and this trend seems to be the similar in the normal population.

In the study by Baltaci, (2001) findings paralleled those found in previous studies (Brown et al., 1988; Bigliani et al., 1997), namely that there was an increase in external rotation and a decrease in internal rotation at $90^\circ$, comparing the dominant to the non-dominant side. The reason for these changes could possibly be due to the adaptive response caused by continued overhead motion, inborn glenohumeral joint characteristics, or because of changes in humeral torsion.

During the cocking phase of baseball pitching maximal external rotation takes place, which has been reported to be between $160^\circ$ and $185^\circ$ (Fleisig et al., 1995). In this maximal external rotation component, scapulothoracic motion and trunk hyperextension are also involved. There was no significant difference found between the two sides when external rotation was done with the arms at the side. On this basis it could be inferred that this increase in external rotation could directly reflect the throwing mechanism.
Baltaci (2001) found that the difference in internal and external rotation between the dominant and non-dominant side, was probably directly related to the high degree of external rotation that takes place when the arm is at 90° of abduction while pitching, but it is not directly related to the amount of internal rotation needed to deliver a pitch. Because of the throwing motion, there is a physiological adaptation in the motion of the shoulder. There is a stretching of the anterior capsule and tightening of the posterior capsule (Brown et al., 1988). According to Baltaci (2001), it has not been shown, but tight posterior shoulder tissues may contribute to some loss in the shoulder rotation range of motion.

In yet another study, the only significant range of motion difference that was found between baseball players and control groups (age, height and weight matched boys who did not play throwing sports) was the forearm pronation range of motion that was greater in the baseball group. In the other range of motion measurements taken (internal and external rotation, elbow flexion and extension or forearm supination) there was no significant differences (Clements et al., 2001). There was an increase in shoulder external rotation and decrease in shoulder internal rotation in the adult baseball players, but this may not have been present in their adolescent years. The adolescent baseball player does not throw often enough to allow for the extreme rotation required during late cocking, which in turn stretches the anterior joint structures so that there is an increase in external rotation (Clements et al., 2001).

All adolescents may have a significant amount of external rotation range of motion regardless of the sport in which they participate. If movement in soft tissue is not actively maintained, the tissue stiffens with age, eventually reducing movement (Boone & Azen, 1979; Mints & Dviri, 1988). The change in range of motion in the adult baseball players may not have been seen in the early adolescents, because of the fact that they have not played baseball for a sufficient number of years for the changes to take place. There was an increase in the shoulder external rotation and a decreased shoulder internal rotation (Clements, et al., 2001).

According to Andrews and Gillogly (1985), the throwing athlete should present an increase in external rotation and a decrease in internal rotation. If this does not occur,
it is believed that it is an indication of pathology. Altchek and Levinston (2000) explained that the first factor required in a throwing athlete is extreme range of motion. In a study done on pitchers – where the throwing action involved the arm to be abducted approximately 90° – significantly less shoulder flexion was present in their dominant arms when compared to the non-dominant arms, which is also an indication of the throwing action. It might well be because of the shoulder not being taken into the full range during the throwing action (Pappas et al., 1985).

When comparing the dominant and the non-dominant shoulders of elite throwers, an increase in external rotation could be expected. Many throwing athletes also show a loss of internal rotation of the dominant shoulder, which may be ascribed to the contracture of either the posterior cuff or posterior capsule. It is common for throwing or serving athletes to develop a higher internal-external rotation strength ratio (Altchek & Levinson, 2000).

During the throwing actions extreme stresses placed on the shoulder could lead to several adaptive changes taking place (Andrews & Gillogly, 1985; Pappas et al., 1985). Amongst these adaptive changes that take place, shoulder ROM is dominant. An increase in external rotation and a decrease in internal rotation have been observed in the dominant arm of baseball pitchers (Andrews & Gillogly, 1985). The increase in the external rotation could contribute to a greater velocity when the ball is released, because of the improved efficiency of the internal rotator muscles (Brown et al., 1988). The cause of the decrease in the concentric external rotation may be because of the eccentric overload, which causes musculotendinous microtrauma or suprascapular nerve injury (Wang, et al., 2004).

The role of range of motion in the throwing action

During the throwing motion when the arm is externally rotated at the end of the cocking phase to prepare for the throwing motion, the internal rotators and horizontal adductors are stretched in such a way as to explode the humerus into internal motion during the acceleration phase (Pappas, et al., 1985). The throwing motion is an
extremely complex motion, which requires high-energy forces to successfully complete the throw. Because of this high demand placed on the shoulder, it may eventually lead to joint instability. Chandler, et al. (1990) and Kibler et al. (1996) concluded that there is a complex interaction of strength and flexibility required to successfully complete the throwing motion. The shoulder structures need to maintain appropriate stability, but still allow functional motion to take place (Boublik & Hawkins, 1993).

K. POWER GENERATION

1. Factors that influence power

When the arm gets accelerated during the humeral internal rotation, velocities can reach over 6 000 °/sec (Pappas, et al., 1985). In a study on 18 elite adolescent baseball players (age 13–16 years), playing baseball for an average of 6.6 ±1.9 years, a moderate correlation (r=0.4336, p=0.082) was found in the concentric shoulder internal rotation peak torque-to-body weight, but it was not significant in terms of the throwing speed (Clements et al., 2001). It was found that concentric shoulder internal rotation peak torque contributes minimally (6-10%) to the throwing speed in baseball players (Pedegana et al., 1982; Bartlett et al., 1989).

A muscle need a stable base of origin, otherwise it cannot develop the appropriate or maximal torque when a concentric contraction is performed, thereby decreasing the force produced. This contributes to problems with the force production, as well as muscle imbalances (Kibler, 1998).

One of the most important abnormalities in atypical scapular biomechanics is the loss of the link function in the kinetic chain. If the scapula becomes deficient in motion or in its position, the transmission of the major forces generated from the lower extremities to the upper extremity, is impaired. This causes a reduction in the maximum force that can be delivered to the hand, or it creates a situation of “catch-
up” where the most distal parts have to work harder to compensate for the loss of proximally generated forces (Kibler, 1998).

When there is a 20% decrease in the kinetic energy delivered from the hip and trunk to the arm, an 80% increase in the mass or a 34% increase in the rotational velocity at the shoulder are needed to deliver the same amount of resultant force at the hand. When the scapula is unstable, the base for glenohumeral rotation is not stable and, therefore, the arm operates off an unstable platform and consequently decreases the efficiency of the entire motion (Kibler, 1998).

Cohen (1994) found that the multiple measures of both flexibility and strength in the dominant arm of the tennis player are related to the velocity of the serve. The aim of the study done by Warner et al, (1990) was to quantify and report the patterns of flexibility, laxity and isokinetic strength in asymptomatic shoulders, and on shoulders with some instability and impingement syndrome. He found that there were significant differences between the nondominant and dominant shoulders of normal subjects, with the dominant shoulder demonstrating significantly greater internal rotation strength compared with the non dominant side. It was also found that anterior instability of the glenohumeral joint was associated with excessive external rotation, and a relative weakness of the internal rotators of the shoulder.

**The internal/external rotation ratio**

In overhead sports it is important for the athlete to have a proper ratio of eccentric antagonist to concentric agonist, or better described, as the functional relationship between medial and lateral rotators. The ratio between the internal and the external rotators is important so that optimal functioning may take place without injury. When the muscles of the stabilisers become fatigued, it can lead to subtle losses of dynamic stability and increased stress to the capsule (Altchek & Levinson, 2000).

The strength of the external rotators is essential for glenohumeral stability and there is a possibility that this greater strength could play a role in protecting the shoulder from
shoulder pathologies (Stanley et al., 2004). If the ratio of internal and external rotation is analysed it is best is to ascertain the strength of the antagonist muscle group firing eccentrically compared to the agonist muscle group firing concentrically in the end range, where the antagonist is then functioning as a decelerator (Scoville et al., 1997).

Alderink and Kuck (1986) determined the ratio between the strength of the internal and external rotators to be 3:2. However, evidence suggests that there is a difference in internal rotation between the dominant and non-dominant arms.

There has been a few studies comparing the relative ratio between the internal and external rotators, as well as the difference in ratio between the dominant and non-dominant side. In the study by Wang et al., (2004), the occurrence of relative weakness of the external rotator muscles in the dominant arm seems to be distributed widely amongst elite volleyball players. This weakness is more likely to be ascribed to the early stages of adaptation due to the repetitive throwing action, than directly related to the occurrence of shoulder injury because of repetitive internal and external rotation. In another study done with the normal, healthy population, the ratio of the shoulder internal/external rotational strength was approximately 1.5 in men, with no difference between the dominant with the non-dominant side (Hageman, et al., 1989). The same study found that the ratio for the female population was between 1.12 and 1.56, but neither was there any difference between the two sides. In a study by Ellenbacker (1992) highly skilled tennis players were tested, and it was found that both the males and females had significant greater internal rotational strength in the dominant side, but no detectable difference in the external rotation comparing the two sides of the body.

A study undertaken on swimmers (Carter, 1964) measured isokinetic strength concentrically. It was found that the ratio of the external rotators: internal rotators to be 0.64. This was significantly different from the group tested by Warner (1990). The lower ratio in the swimmers could be ascribed to the greater internal strength developed in the swimmers due to their specific swimming motions. The increase in the internal rotators strength in athletes using overhead throwing actions suggested
that the external rotators are strengthened to keep the ratio higher. The lower ratio may expose the shoulder to more injuries than a higher ratio (Pappas et al., 1985). It is unknown whether the injuries are related to the actual imbalance, or only to the excessive overhead activity (Bak, 1997). It has been recommended that the norm range of external/internal rotation ratio should be 0.6 – 0.7, but due to variation in testing procedures, the acceptable external/internal rotation ratio has been changed to 0.5-0.7 to accommodate these variations taking place during the testing (Hartshell, 1998/1999).

The ratio usually taken is the ratio of the internal rotators contracting concentrically to the external rotators rotating concentrically. With the throwing action, the internal rotators contract concentrically, and there is more eccentric contraction in the external rotators due to the deceleration that needs to take place, and the centring of the humeral head. Thus expressing the ER:IR as concentric: eccentric is a more functional ratio that could be evaluated (Bak, 1997).

In other studies the external/internal rotation ratio was established by using the sagittal and frontal planes. It generally could be accepted that the internal rotators could be significantly stronger than the external rotators, with a of 3:2 ratio, when concentric contractions for both the internal and the external rotations were used (Alderink & Kuck, 1986; Hinton, 1988; Brown, et al., 1988; McMaster, et al., 1991). The delivery of a high performance pitch may be determined by the ratio (3:2) of the shoulder internal/external rotation, but it seems more to be the pure strength of the muscle groups that proves to be important. The internal rotation muscles, which compromise the latissimus dorsi and the pectoralis major, are most likely responsible for the internal rotators being stronger. The external rotators produce high activity when the arm is decelerated. It would seem that it is not the ratio that plays an important role in the delivery of a high performance pitch, but more specifically the pure strength of the different muscle groups (Brown, et al., 1988).

According to Bak (1997), pain-free shoulders have a significant lower concentric and eccentric ER:IR ratio strength measures compared to painful shoulders. A study found that the length-tension relationship during rotational motion is an important
determining factor of peak torque generation and thus when testing takes place outside the extremes, the true peak torque may be overlooked (Hartshell, 1998/1999).

Aldernick and Kuck (1986) tested high school and college-aged pitchers, investigating the isokinetic strength in the shoulder of the throwing athletes. The external/internal peak torque ratio, as reported, was about 2:3, which was not speed specific. In another study by Hinton (1988) the findings by Aldernick and Kuck (1986) were confirmed. It was determined that a water polo player has a double risk of developing imbalances in the shoulder because of the combined effect of the swimming and the throwing actions during the game (McMaster et al., 1991).

Cohen (1994) found a significant relationship between the serve velocity and the strength and flexibility that the tennis players displayed. It was found that there was an imbalance of the IR: ER torques 4:3 in the serving shoulder. The degree of the torque imbalance could be used to predict serve velocity, and those athletes with greater imbalances produce higher velocities in their serving action. Chandler (1990) was one of the authors who suggest that muscle imbalance may be responsible for the high prevalence of shoulder injuries found in these athletes.

There is a complex chain of motions that constitutes the tennis serve, which depends on the technique used, with sequential activation of body parts through a link system of all body segments (Cohen, 1994; Pappas, 1985). And thus the relationship of muscular strength and flexibility around the shoulder joint, compared to the performance outcome, should not be over-emphasised, although it was found that there is a relationship between multiple measurements of both flexibility and strength in the tennis player’s dominant extremity and the serving velocity (Cohen, 1994).

Scoville et al. (1997) found that the ratio of external rotators contracting concentrically compared to the internal rotators also contracting concentrically had a ratio of approximately 2:3. The external rotators acting as antagonistic for eccentric contraction and internal rotations acting as the agonistic contractions being contracted concentrically, showed a ratio of 1.08:1 with reference to the dominant shoulder.
The ratios commonly reported are the concentric agonist/concentric antagonist or the eccentric agonist/concentric antagonist. These ratios provide guidelines for the evaluation of patient strength, but they may not constitute true muscle functioning during the activity and, therefore, these may overlook important muscle imbalances. It has been proposed that the most important values may be those of the eccentric antagonist/concentric agonist ratio. The eccentric antagonist should have sufficient strength to overcome and decelerate the strength and momentum accompanying the motion, and thus a ratio of greater than 1:1 could be expected. As the speed of testing increases, the concentric force generated decreases, and the eccentric forces remain the same or increase. It also results in an increase in the ratio of the eccentric antagonist/concentric agonist ratio. This suggests that to obtain a more sensitive ratio, testing should take place at lower testing speeds (Scoville et al., 1997).

It is important for throwing and serving athletes to display a proper ratio of the eccentric antagonist to the concentric agonist muscles. The proper ratio is critical for dynamic stability and optimal functioning. This ratio may better be described as the functional relationship between the internal and external rotators. The analysis of strength that is most applicable to function, may be to compare the antagonist muscle group firing eccentrically to the agonist muscle group firing concentrically when the antagonist is firing as a decelerator, thus at the end range (Scoville et al., 1997).

When the arm is externally rotated, the internal rotators experience an eccentric contraction, because they act as antagonists to the external rotators to decelerate, and the external rotators fire concentrically as the antagonists. When the arm is rotated medially, the external rotators contract eccentrically as the antagonist to decelerate the concentrically contracted internal rotators, acting as the agonist (Scoville et al., 1997).

At the end range of throwing, the external rotation is found to be between 60º and 90º. At this position, the eccentric antagonists are significantly stronger than the concentric agonists. The ratio in the dominant shoulder is 2,39:1 and for the non-dominant shoulder is 2,15:1 (Scoville, et al. 1997).
When adult pitchers were tested at 180-300°/sec, they tended to demonstrate a decreased concentric external rotation peak torque in the dominant arm, but with the internal rotation there was either no difference or an increase in the peak torque (Cook et al., 1987; Wilk et al., 1993). When comparing testing speeds of 60°/sec through to 180°/sec, the external to internal rotational strength ratio was found to be 2:3, and no changes in the ratio were found between these speeds. When considering peak torque ratios, it was found that the external to internal rotation was 2:3 with a 5% change as the tests increased from 90°/sec to 300°/sec (Hinton, 1988).

In the throwing motion during the deceleration phase, a large eccentric force is placed on the posterior rotator cuff group. It has been shown that the eccentric muscle action causes intramuscular connective tissue tearing. When this intramuscular connective tissue tearing takes place, it could lead to chronic inflammation and muscular weakening. One could state that the internal rotator muscles and the adductor musculature undergo a plyometric type of training with each pitch.

Wang (2004) studied elite volleyball players in isokinetic tests at speeds of 60° and 180°. They found that an imbalance in the rotator cuff muscle strength played an important role in shoulder injuries in these athletes. When elite volleyball players were tested for muscle imbalances, it was found that where the average external rotation eccentric torque production in the dominant arm was less that the concentric internal rotation, these athletes were more likely to have an injured or painful shoulder.

It was found that athletes with a past history of shoulder pain had a lower ER strength in the dominant side comparing it to the non-dominant side that had no history of pain. When comparing the sides in the strength of the IR or in the ratio of IR/ER, there was no difference (Stanley et al., 2004). There was a negative correlation between the peak torque and age (p<0.001), but no relationship with body mass (P>0.54), height (P>0.08), hours of play (P>0.09), or use of double backhand (P>0.06) when compared to peak torque (Stanley, et al., 2004). The decrease in the external to internal rotational peak torque ratio generally seen could be caused by
either the decrease in external rotation strength (Alderink & Kuck, 1996), or because of the increase in internal rotational strength (Hilton, 1988).

When playing an overhead throwing sport, large stresses are exerted on the shoulder when throwing. These stresses could be ascribed to the large angular velocity produced with the throw, which may range from 6000 to 7000°/sec, and also the many repetitions of the throwing motion required during a game (Dillman et al., 1993; Pappas et al., 1985).

There are specific adaptations, such as the increase in external rotation in abduction, that result from the throwing mechanism. There is also significantly less horizontal extension in the dominant arm. The decrease in motion could be the result of tightness only in the one-side of the pectoralis major muscles. The pectoralis major, together with the latissimus dorsi, act in decelerating the externally rotating shoulder during the late-cocking phase. The pectoralis major assists the subscapularis in moving the arm across the chest during the follow-through phase. Because of the repetitive stress during the throwing and the non-use of its available range of motion, the pectoralis major tightens. In the throwing arm of pitchers hypertrophy of the pectoralis major and the latissimus dorsi has been observed (Brown et al., 1988).

There is significantly less shoulder flexion in the dominant arm when compared to the non-dominant arms in pitchers, which reflects their throwing mechanism. When the ball is released, the arm is abducted at about 90° (Pappas et al., 1985). The significant decrease in the shoulder flexion may also be the result of the non-use of the full range of motion during the throw. There is also a significant decrease in the dominant arm’s internal rotation of the shoulder at 90° of abduction. At the start of the acceleration phase the dominant arm is powerfully rotated internally from a position of maximum external rotation (Brown et al., 1988).

The throwing athlete has to maximally accelerate and decelerate the arm over a short period of time, and at the same time should maintain control over the object being thrown. This places extreme demands on the shoulder. Because of the high loads generated by the thrower, it puts significant stresses on the soft tissue structures
responsible for shoulder stability. These structures are the labrum, the capsule and the tendons of the rotator cuff (Altchek & Hobbs, 2001).

It has been shown that concentric shoulder adduction, wrist extension and elbow extension peak torque act as significant predictions of the relevant throwing speed in adult baseball players (Bartlett et al., 1989; Pedegana et al., 1982). It has been predicted that only 53.1% of the throwing speed can be attributed to the upper limb involvement, and the rest is a complex act involving all of the body parts that form a kinetic chain to generate the energy (Toyoshima et al., 1974). The muscles of the upper limb work isometrically, concentrically and eccentrically during throwing to produce movement, and they equally work to decelerate and accelerate movement and to stabilise the upper limb joints, especially the shoulder joint (Jobe, et al., 1983; Jobe, et al., 1984). In order to throw properly and efficiently, coordination among the upper limb muscles, and with the trunk and lower limb is essential. To increase the throwing speed without exposure to an increased risk of injury, players have to learn to coordinate their muscle activity within the throwing arm. The motion of the throwing arm also needs to be coordinated with the rest of the body (Toyoshima et al., 1974).

The overhead throwing motion is a skilful movement that is stressful on the shoulder joint and complex. The overhead athlete places extraordinary demands on the shoulder complex, because of the tremendous force that the thrower generates. The shoulder of the thrower must be lax enough to allow excessive external rotation, but also stable enough to prevent humeral head subluxation; thus requiring a delicate balance between mobility and functional stability. Because this balance is frequently compromised, it may well lead to injury. Repetitive stresses placed on the throwing athletes shoulder joint complex challenge the shoulder’s physiological limits of the surrounding tissue. When alterations in the throwing mechanics take place, including muscle fatigue, muscle weakness or imbalances and excessive capsular laxity, these may lead to tissue breakdown and injury (Wilk, 2002).

L. SUMMARY
It is possible to conclude that there are several factors playing a role in the action of throwing, and many studies have been done to explore the different aspects. Many different muscles are involved in throwing, and they all play their own unique role in this throwing motion, some of them in terms of acceleration, some stabilising, while others are involved in deceleration. One main point that can be made is the fact that the kinetic chain plays a tremendously important role in the throwing action. One could also observe that there are many different actions and characteristics involved in each sport. Cricket is played over a large surface area and the ball has to travel much further when compared to netball, where the court is much smaller and the ball has shorter distances to travel. All players are asked to execute a powerful throw.

The shoulder complex consists of four joints, namely the sternoclavicular joint, the acromioclavicular joint, the glenohumeral joint and the scapulothoracic joint. Various different muscles are involved in the shoulder complex, including the rotator cuff muscles consisting of the infraspinatus, supraspinatus, subscapularis and the teres major. Added to the above, one should also bear in mind the roles of the infraspinatus, teres minor, supraspinatus, subscapularis, serratus anterior, rhomboids, upper trapezius and levator scapula, pectoralis minor, deltoids, and the latissimus dorsi. These muscles are all important for certain functions in the shoulder, and all are indispensable for throwing the ball optimally.

Throwing may be divided into different stages, the first of which is the winding-up phase where the thrower prepares him/her for the throw. The next stage is the cocking phase, where the arm reaches maximal external rotation. This is why it is thought that the range of motion needs to be increased when the athlete is ready to throw the ball. Thirdly, the acceleration phase follows, in which the arm rotates forward and reaches maximal speed for the ball to be released, and then finally the follow-through phase takes place after the ball is released.

Core stability is use more commonly lately, but there does not seem to be any certainty as to what exactly this entails. Because core stability involves the deep muscles, it is extremely difficult to test these muscles. In addition, there is a lack of
research literature on accurate and valid tests to measure core stability, except those using invasive methods. Because the core is seen as the connection between the lower limbs which generates most energy, and the upper limbs, one could thus suspect the core to be stronger in those athletes who throw further, so that the energy transfer takes place more efficient. As described earlier, these muscles could provide different stabilising functions.

The range of motion of the shoulder complex is also considered as one of the important physical factors to consider with regard to the performance of the shoulder joint. It might be said that an increase in range of motion is expected for more momentum generation, thus increased power output and further throwing distances. The main range of motion on which this study concentrated, is that of the shoulder internal and external rotation, which are the main actions that take place in the shoulder when the athlete is throwing the ball.
CHAPTER THREE

METHODOLOGY

A. INTRODUCTION

This study analysed some physical factors that could influence the action of distance throwing in cricket and netball. The athletes aim to throw the ball as fast and accurately to the next person as possible and, moreover, doing this injury free. A cricket field is much larger than a netball field and thus the distance cricket players have to throw the ball is further than netball players. This implies that throwing in netball is much quicker and in short throws; whilst in cricket longer throws are the norm. All players have to make powerful throws. The question now arises as to what factors influence the speed and the distance that the ball is thrown. Furthermore, are there different factors affecting netball when compared to cricket because of the nature of the relevant sports?

B. SUBJECTS

A group of volunteer subjects was drawn from the local netball and cricket clubs of the Stellenbosch environment. They were selected because the distance for travelling to the University of Stellenbosch for the purposes of testing would not present any problem. The subjects were mainly members of the University of Stellenbosch netball and cricket clubs. Thirty nine subjects participated in the study, of whom twelve (n=12) were male and twenty four (n=24) female. Both local clubs and sports science students were contacted to recruit subjects for the study.

Letters to explain the study, and the tests to be done, were handed out to individuals who showed an interest to participate in the study. These athletes were contacted telephonically to confirm that they met the requirements, and an appointment was made for the testing to take place.
The competition level ranged from fifth team at club level to national and international participation.

**Inclusion criteria**

Each athlete had to meet the following criteria for inclusion:

- Play competitively at club level during the specific season.
- Be older than 18 years.

**Exclusion criteria**

The subjects may not have had operations in the dominant shoulder. They had to be free of injury and not have been experiencing any form of pain in their shoulders for the last three months prior to testing.

**Informed Consent**

All testing procedures and the risks involved in participation were explained to the subjects before testing started. There was also an opportunity before testing to ask questions in the possible event of the subject being unsure of any aspect, or needed to know more. The athletes agreed to all testing requirements and procedures by giving their written consent.

**Questionnaires**

On arrival at the testing laboratory, the subjects received a questionnaire (Addendum A) and a consent form (Addendum B) to complete. The subjects had a brief overview of what the testing entailed, and guidance through the forms they had to fill in, whereupon time was allowed to ask questions.

The questionnaires consisted of personal information, questions regarding the years of participation in the relevant sport, any other sports in which they took part, hours
spent on training and the level of participation. It also required relevant medical history and previous injuries that they might have experienced, and particulars on the onset of any such injuries.

C. PROCEDURES

The tests were selected so as to explore the physical factors that may play a role in the throwing of the ball. The physical factors that were selected encompassed the distance that the subject was able to throw, kinantropometric measurements, core stability, range of motion of the joints in the upper body and isokinetic strength in the subject’s upper limb. There are various tests that assess these factors, but the relevant tests were specifically chosen because of their validity and reliability.

Most of the measurements were done on one day in a specific order. The factors that were tested and measured were:

- Kinanthropometric profile
- Core stability
- Distance throwing
- Isokinetic strength
- Range of motion

The parameters of the tests battery conducted for the measurement of the different components are reflected in the table below.
Table 3.1: Summary of the test battery for the different physical factors tested.

<table>
<thead>
<tr>
<th>Component</th>
<th>Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinanthropometric profile</td>
<td>Stature, body mass, 3 skinfold, 2 breadths, 6 circumferences, 4 lengths measured</td>
</tr>
<tr>
<td>Core stability</td>
<td>Leg drop test with stability cuff, prone walk out test</td>
</tr>
<tr>
<td>Distance throwing</td>
<td>Seated on chair strapped in and free sitting</td>
</tr>
<tr>
<td>Isokinetic strength</td>
<td>Concentric/concentric and concentric/eccentric at 2 different speeds</td>
</tr>
<tr>
<td>Range of motion</td>
<td>Internal rotation, external rotation, supination, pronation, lateral flexion, elbow flexion, elbow extension, wrist flexion, wrist extension</td>
</tr>
</tbody>
</table>

**Test administrators**

Three post-graduate students from the Department of Sports Science, Stellenbosch University, acted as test administrators. They all had experience in testing. Each received a list of written testing procedures and protocols, and every test was explained to them orally, whereupon they were shown exactly how the testing should be performed. The test administrators then had the opportunity to practice the tests, and ask questions regarding any uncertainties. They were assisted by the researcher during the first test to ensure that the testing was done correctly. Each of the three administrators had specific testes that they had to administer.

**Experimental design**

This was an empirical design where the chosen subjects were tested once only without any intervention programme. On arrival the subjects completed a questionnaire and a consent form, and were briefed on the procedures of the test. A measurement of stature and body mass was done to start the testing. Thereafter the subjects were
photographed for range of motion in different positions, without any warming-up or stretching before the range of motion test. Then the subjects performed the two core stability tests on the exercise mat in random order. The isokinetic testing on the Biodex was preceded by a warm-up on the arm ergometer. On the Biodex the first test involved the concentric/concentric 90°/sec; then the 180°/sec test; and followed by the concentric/eccentric 90°/sec and then the 180°/sec test. After these tests, the skinfolds, girths, lengths, and breadths were measured. Throwing for distance test was done indoors on a second day of testing. These tests were performed indoors in order to eliminate the effect of wind or changing weather conditions.

D.  MEASUREMENTS AND TESTS

1.  Isokinetic testing

The isokinetic testing was done to investigate the ratio of internal and external rotators in the dominant shoulder only, and it also observed the power and torque generated. In doing this test, the isokinetic internal/external rotation, was done both concentric/concentric and concentric/eccentric on the Biodex System 3 machine.

The subjects had a 5 minutes warm-up on the Monark 881 arm ergometer at an intensity of approximately 3 cal.min⁻¹, and at a speed that was comfortable for the subject (±25 watts). Prior to testing, each subject received a brief explanation on what to expect from the test. Thereafter the subject was instructed to sit in the Biodex System 3 chair and adjustments were made for the correct anatomical positioning of each subject. The back rest was adjusted so that the bend of the knee was at the end of the seat. The chair of the Biodex was set at an incline of 80° and 0° rotation, and the dynamometer was tilted 0° and rotated 90°.

During all tests pelvic and chest straps were used to stabilise the trunk to prevent the recruitment of trunk muscles. These are standard straps on the machine. The chest
straps were strapped across the chest in a cross. There was a waist strap that was straped over the upper thighs. Each subject was allowed 5 to 7 warm-up repetitions on the machine at the test speed. After warming-up, each subject was instructed to perform 5 maximal repetitions. During the testing no verbal encouragement was given, as suggested by Barlett (1989).

The testing was undertaken in the scapular plane because of the more natural position of the shoulder and the less complex movement to be done. In the scapular plane, the inferior part of the capsule is not twisted and the humerus remains in neutral rotation (Hartsell, 1998/1999). The use and efficacy of the 90° abducted and 20° forward flexion, known as the scapular plane isokinetic-testing position has been demonstrated elsewhere (Ellenbecker, 1992; Hinton, 1988). The subjects were seated with their forearm resting on a padded V-shaped trough and a strap secured the forearm in place. The trunk of the subject was positioned at 90° to the dynamometer with the arm positioned in 45° abduction and elbow positioned in 90° flexion.

The athletes were tested for both internal and external rotation at two speeds (90 and 180deg/sec) for concentric/concentric as well as concentric/eccentric contractions. These speeds were chosen because of the increased risk of injury relating to eccentric testing at higher speeds (Davies et al., 2000). The body was stabilised at the hips and trunk with self-adhesive straps. The first test was the 90°/sec concentric/concentric shoulder internal/external rotation, then the 180°/sec concentric/concentric shoulder internal/external rotation. Then the concentric/eccentric testing was done firstly at 90°/sec and then at 180°/sec.

Each subject had to internally and externally rotate the shoulder with the greatest force possible when executing the concentric/concentric contractions, whilst with the concentric/eccentric contraction the arm was internally rotated with the greatest force possible. The arm was then held in the internally rotated position as strongly as possible, while the machine would try to push the subject’s shoulder into an externally rotated position.
2. Distance throwing

The aim was to determine the distance that the athlete was able to throw, not using the lower limbs to generate the power, but only the trunk and the shoulder muscles. The reason for this is to keep the effect of the kinetic chain out of the equation and focus on the power generated in the shoulder joint.

The subject was seated on a chair that was 45.5 cm high and had a back rest that was 50 cm high. The test was performed indoors on a smooth, hard surface this was to eliminate any wind resistance that was outdoors, as well as the surface of the grass that might influence the delivery height due the chair sinking into the grass. The ball used for the test was a 1-kg medicine ball, Gymnic line, Heavymed. This 1-kg medicine ball was used because of the difference in size of the balls used in the
different sports in which the subjects participate, and it is also an objective measured unit. Six cones were used to mark the spot on which the ball landed and a 25m measuring tape was used to measure the distance. A strong nylon ribbon was used for strapping the subject to the chair. This ribbon was six centimetres wide and had an adjustable clip to adjust the width for each individual subject.

The subjects were given the opportunity to warm up their shoulders and stretch before throwing began. The chair was then placed on the line at the one end of the hall, and the subjects were seated on the chair, knees facing forward. Throwing had to take place with their dominant hand, doing a shoulder throw. The subjects had three throws seated freely on the chair, and the aim was to throw the ball as far as possible without lifting off the chair or transferring their weight onto the feet. After the first three throws, subjects were strapped onto the backrest of the chair and had to keep the trunk immobile while throwing. The subjects again had three throws to complete. The tape was strapped across the chest at the height of the xiphoid process, and for the ladies just under their chest. The spot on which the ball first touched the ground was marked with a cone. After throwing, the measuring tape was placed on the floor in a straight line, with the end on the line where the chair was placed. A line was then drawn from the beacon perpendicular to the measuring tape to establish the distance of the throw.

The distance of the throw was measured to the nearest centimetre (cm) from the line on which the chair was placed to the spot where the medicine ball landed.
3. Core stability assessment

The aim of the core stability tests was to assess the stability of the athletes in the most objective way possible. Two tests were used for the assessment of core stability, namely the one minute modified leg lift test, and the prone one minute walk out.

For the one minute modified leg lift test, a mat, stopwatch and stability cuff (stabiliser pressure bio-feedback, ISO 9001/ISO 13485) were used. For the prone one minute walkout test a mat, a swissball, a stopwatch, and masking tape were needed. The size of the swissball was chosen according to the stature of the subject.
One minute modified leg lift test

The one minute modified leg lift test was done with a stability-testing cuff. The cuff was placed under the subject’s lower back so that the bladder of the stability cuff was positioned on the most curved part of the lumbar spine. The subjects had to lie on their back, with hips and knees at 90º angles and their lower legs parallel to the floor. Their arms and hands were placed behind their heads. The pressure cuff was inflated up to 40 mmHg. The subjects had to lower their legs, by extending their hips and keeping their knees at a 90º angle, until their heels touched the floor, and then returned to the starting position. Throughout the movement the subject had to maintain a steady pressure on the cuff. The number of repetitions in one minute were counted. A repetition was not counted if the pressure in the cuff dropped 10 mmHg above or below 40 mmHg. The subject was allowed to look at the pressure gauge during the test. This test measures the stabilising function of the deep muscle system or local stabilisers in lumbar spine and pelvic region (Olivier, 2005; Kroff, 2004).

![Starting position of the leg drop test](image)

Figure 3.3. Starting position of the leg drop test
Prone one minute walkout

In the one minute walkout test subjects had to position themselves in a prone position, with their upper legs on the top, middle part of the stability ball with their hands on the floor and their arms straight, perpendicularly to the floor. A line was drawn with masking tape on the floor at the tips of the subjects’ middle fingers to indicate the starting position. The subjects rolled forward on the ball until their shins were on the top, middle part of the ball. A line with masking tape was drawn on the floor at the back of the hands of the subjects to indicate the end position. The subjects were instructed to move back and forth between the starting and end positions as quickly as possible, without losing their balance on the ball. The number of repetitions in one minute was measured. A repetition was not counted if the subjects’ hands were not behind the tape at the starting position and not over the tape at the end position. The subjects had to maintain good form throughout the test, suggesting that the back should be straight. The test was terminated if the subjects fell off the ball. This test measures the core strength of global stabiliser muscles (Olivier, 2005; Kroff, 2004).
Figure 3.5. Prone one minute walkout at end position

Figure 3.6. Prone walkout test being performed
4. Range of motion

The aim of the range of motion tests was to determine the amount of range of motion in the various joints used in the throwing motion. The main focus of this study was on the shoulder joint, but the wrist, elbow and back side flexion was also investigated.

There were several positions where the range of motion was calculated, namely wrist flexion, wrist extension, wrist pronation, wrist supination, elbow flexion, elbow extension, shoulder internal rotation at 90° of abduction, shoulders external rotation at 90° of abduction, all on the dominant side and lateral flexion to both sides.

A table, a box, an eye line and camera was needed for the testing. The camera used was a Canon Powershot A95. Before the testing started the subjects were first marked with eyeliner so that the landmark could easily be recognised on the photos. The markings were made on the cervical vertebrae 7 and at approximately lumbar vertebrae 5. The mid-point of the deltoid was also marked, as well as the lateral malleolus of the wrist and elbow.

After applying the marking, the subject was seated in an upright manner, and the box adjusted so that the subject’s elbow was comfortably placed on the box. With the wrist pronated (palm facing to the floor), the subject flexed the wrist and then extended it as far as possible while keeping the fingers straight.

Wrist pronation and supination

A pen was placed in the subject’s hand, still sitting upright and the elbow directly below the shoulder and the hand clinging the pen in a fist. Next, keeping the arm still, the subject pronated the wrist (palm towards the floor) as far as possible keeping the fingers in a fist, and then supinated (turning the palm towards the ceiling).
**Elbow flexion and extension**

For the next range of motion tests, the box was elevated so that the upper arm was resting on the box with the shoulder flexed $90^\circ$ forward. The subject placed the upper arm on the box with the elbow hanging off the side, and then extended the elbow as far as possible. Remaining in this same position, the elbow was flexed as far as possible.

**Shoulder internal and external rotation in a $90^\circ$ abducted position**

The subject assumed a supine position with the side of the table in line with the glenohumeral joint. With external help the subject’s shoulder was pushed down to prevent it from lifting off the table and then the shoulder was internally rotated. In this same position the shoulder was also externally rotated, keeping the shoulder abducted at $90^\circ$ and not allowing to drop the arm below the level of the body.

**Lateral side flexion**

In the last measurement the subject stood facing a wall against which a straight line was drawn. The line had to run through the middle of the body while standing upright, with the feet hip-width apart. The subject then had to flex laterally to the side, neither leaning forward nor to the back.

**Measurement of the angles**

In each of these positions the subject moved into the position described and a photo was taken of the subject in that position. The photos were then printed out and lines were drawn through the identified landmarks. The lines then formed an angle, which was measured, which was then described as the range of motion in that particular
joint. This method of determining the range of motion was used because of the smaller variance it offered compared to goniometric measurements (Fish & Wingate, 1985)

**Wrist flexion and extension**

A line was drawn through the lateral malleolus parallel to the line of the box. The next line was drawn through the lateral malleolus through the front of the dactylion (the most distal point of the third digit). This was repeated with the wrist in both positions. The measurement for flexion was the angle from horizontal to the hand in flexion and the extension angle was the angle from the horizontal to the line of the extended wrist.

**Wrist pronation and supination**

The subject was holding a pen with his/her hand in a fist. A line was drawn through the mid-point of the shoulder, running parallel to the vertical edge of the box. The line of the pen was extended to from the second line. For supination the angle lay between the vertical line and the line was extended where the thumb was in terms of the pen. The same angle was used where the pronation was measured.

**Elbow flexion and extension**

A line was drawn through the mid-part of the deltoid and then through the lateral malleolus of the elbow. Another line was drawn through the lateral malleolus of the elbow and through the wrist. The angle measured was the large angle with which the two lines intersected each other.
Shoulder internal and external rotation in a 90° abducted position

One line was drawn parallel to the edge of the table, and the next line was drawn through the lateral malleolus of the wrist through the tip of the elbow.

Lateral side flexion

A line was drawn parallel to a line on the wall. Another line was drawn so that it crossed through the C7 and T5 vertebrae. The angle from the top of the vertical line running through the vertical line on the wall to the line that intercepts the C7 and T5 vertebrae the top part of the line through the vertebrae was then measured.

5. Kinanthropometric assessments

Various kinanthropometric tests were done, including stature, body mass, skinfold measurements, girths, lengths and breadths.

Stature

The stretched stature method required the subjects to stand with their feet together on a hard surface and the heels, buttocks and upper part of the back touching the stadiometer. When placed in the Frankfort plane the head did not need to touch the scale. The Frankfort plane is achieved when the lower edge of the eye socket is in the same horizontal plane as the notch superior to the tragus of the ear. When aligned, the Vertex is the highest point on the skull (ISAK, 2001).

The test administrator placed the hands far enough along the line of the jaw of the subject to ensure that upward pressure was transferred through the mastoid processes. The subject was instructed to take and hold a deep breath, while keeping the head in
the Frankfort plane the test administrator applied gentle upward lift through the mastoid process. The recorder placed the headboard firmly down in the vertex, crushing the hair as much as possible (ISAK, 2001). The height is measured in centimeters

**Body mass**

A standardised electronic scale was placed on a hard and level surface indoors. The scale used was a UWE BW150 (0.1 – 150 kg). Subjects had to stand on the scale and with feet apart and weight spread evenly between the two feet. The subject may not hold, or lean on something. Generally the measuring of mass in minimal clothing is of sufficient accuracy. The scale had a zero reading prior to the subjects standing on the centre of the scale without support and with the weight distributed evenly on both feet (ISAK, 2001). The body mass was rounded off one decimal.

**Skinfold measurement**

Several skinfold measurements were made, which differed between males and females. These measurements were then put into a formula, which determined the percentage of the subject’s body fat. An eyeliner to make the landmarks on the skin, a standardised sliding calliper to measure the distance, and a Harpenden skinfold calliper that determined the thickness of the fold were all necessary.

The percentage of body fat was calculated, using three skinfold measurement as described by Jackson and Pollock (1985). The sites measured for the females were the triceps, suprailium and the abdominal, and for the men it was the chest, triceps and subscapular skin folds. All the anthropometric testing was done by a qualified level one kinanthropometrist.
**Females:**

Body Density (F-3) = 1.089733 - 0.0009245 (X_3) + 0.0000025 (X_3)^2 - 0.0000979 (X_4)

\[
\% \text{ Fat} = \left[\frac{5.01}{BD} - 4.57\right] \times 100
\]

- \( X_3 \) = sum of triceps, suprailium, and abdominal skinfolds
- \( X_4 \) = age in years

**Males:**

Body Density (M-3) = 1.1125025 - 0.0013125 (X_3) + 0.000055 (X_3)^2 - 0.0002440 (X_4)

\[
\% \text{ Fat} = \frac{495}{BD} - 450
\]

- \( X_3 \) = sum of chest, triceps, and subscapularis skinfold
- \( X_4 \) = age in years

(Jackson & Pollock, 1985; Franklin, 2000)

All measurements were taken on the right-hand side of the body, for the right and left handed individuals.

**Triceps**

The subjects assumed a relaxed standing position with the arms hanging by the side. The skinfold was taken on the right side of the body with the elbow extended by the side of the body. Then a parallel fold was taken halfway between the acromion and olecranon processes (mid-acromiale-radiale landmark); in the meantime the elbow should be extended and relaxed (ISAK, 2001).

**Suprailium/iliac crest**

The subjects assumed a relaxed standing position with the right arm abducted or placed across the trunk. The line of the skinfold generally ran slightly downward posterior-anterior, and a diagonal fold was taken laterally above the chest of the illium as determined by the natural fold lines of the skin. (ISAK, 2001) (Jackson & Pollock, 1985).
Chest

A diagonal fold was taken at the distance halfway between the anterior axillary line and nipple for the men (Jackson & Pollock, 1985).

Subscapular

The subjects assumed a relaxed standing position with the arms hanging by the sides. The line of the skinfold was determined by the natural fold lines of the skin. (ISAK, 2001) The measurement was taken at the point 2 cm from the subscapular in a line 45° laterally downward. (ISAK, 2001)

Abdominal

The subjects assumed a relaxed standing position with the arms hanging by the sides. A vertical fold was taken at a distance of approximately 5cm to the right of the omphalion (mid point of the navel) (Jackson & Pollock, 1985)(ISAK, 2001).

Girths

The circumferences were measured of the waist, gluteal area, chest, tense bicep, relaxed bicep and the forearm. The measurements were done indoors and a measuring tape was used to measure the circumferences.

Waist

For the waist measurement subjects assumed a relaxed standing position with the arms folded across the thorax. The girth was taken at the level of the narrowest point between the lower costal border and the iliac crest. When the measuring tape was
placed around the waist, the subjects were instructed to lower their arms to the relaxed position next to their side. The tape was then readjusted as necessary to ensure it did not slip and did not excessively indent the skin. The subjects had to breathe normally and the measurement was taken at the end of a normal expiration (end tidal).

Relaxed bicep girth

The relaxed bicep girth was taken with the subjects’ right arm abducted slightly to allow the tape to be passed around the arm. The girth of the arm was measured at the marked level of the mid-acromiale-radiale and the tape had to be positioned perpendicular to the long axis of the arm.

Tense biceps girth

The subjects’ right arm was raised to approximately 90° of abduction, while the subjects assumed a relaxed standing position. They were instructed to contract the arm muscles as strongly as possible and hold it while the measurement was made at the peak of the biceps. If there was no obvious peak of the biceps, this girth had to be measured at the level of the mid-acromiale-radiale landmark.

Forearm

The forearm girth was taken with the subjects in a relaxed standing position and their right arm relaxed with the elbow flexed at 90° forward. The measurement was taken at the maximum girth of the forearm distal to the humeral epicondyles. The subjects held the palm up, while relaxing the muscles of the forearm.
Chest

The chest girth was taken with the relaxed standing position with the arms hanging by
the sides and slightly abducted. This girth was taken at the level of the mesosternale.
The subjects were instructed to lower their arms to the relaxed position with the arms
slightly abducted. The tape was then readjusted as necessary to ensure it did not slip
and did not excessively indent the skin. The subjects had to breathe normally and the
measurement was taken at the end of a normal expiration (end tidal)

Gluteal

The gluteal girth was taken with the subjects assuming a relaxed standing position
with the arms folded across the thorax. This girth was taken at the level of greatest
posterior protuberance of the buttocks which usually corresponds anteriorly to about
the level of the symphysis pubis. The tape was readjusted as necessary to ensure it
did not slip and did not excessively indent the skin.

Lengths

The aim of this test was to determine the lengths of different body parts, and the
length of the different segments in each limb. The different measurements taken was
the arm span, acromial-radial length, radial-stylion length, and the midstylion-
dactylion length. The apparatus used for the measurement of these lengths was a
measuring tape mounted to the wall, as well as a standardised sliding calliper.

Arm span

A measuring tape was mounted onto the wall at approximately shoulder height.
Masking tape was used to stick the measuring tape onto the wall and a waterruler was
used to get a straight line. The subjects stood with their feet together against the wall
and the tips of their fingers spread out as far as possible. The right hand was put at the 0cm position and then the subject reached to the opposite side were the measurement was taken.

**Acromial-radial length**

For the acromial-radial measurement, the subjects assumed a relaxed standing position with the arms hanging by the sides. The measurement was taken on the right forearm. This length was taken with the one branch of the calliper held on the acromial, while the other branch was placed on the radial.

**Radial-stylion length**

The radial-stylion measurement was also taken with the subject in 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. The measurement was taken with the one calliper branch held against the radial and the other branch then placed on the stylion landmark, whereupon this distance was measured.

**Midstylion-dactylion length**

During the measurement of the midstylion-dactylion subjects again assumed a relaxed standing position with the arms hanging by the sides. The right elbow was partially flexed, forearm supinated, and fingers extended but not hyper extended. This measurement represented the length of the hand, and was taken as the shortest distance from the marked midstylion line to the dactylion. One branch of the calliper was placed on the marked midstylion line, while the other branch was positioned on the dactylion (which is the most distal point of the third digit).
**Breadths**

The breadths give an indication of the skeleton size. The breadths taken were the biacromion breadth, which is an indication of the shoulder width, and the bi-epicondylar breadth which is an indication of the breadth of the humerus.

**Biacromion**

The biacromion measurement was taken with the subjects standing upright in a relaxed standing position with the arms hanging by the sides. The distance that was measured was between the most lateral points on the two acromion processes. This distance was measured with the branches of the large sliding calliper that were placed on the most lateral points of the acromion processes. The calliper branches were held at an angle of about 30° pointing upwards. Pressure was applied to compress the overlying tissues, but care was taken not move the shoulders.

**Bi-epicondylar**

To determine the length for bi-epicondylar humerus, subjects again assumed a relaxed standing position. The right arm was raised anteriorly to the horizontal and the forearm flexed at right angles with the arm. A sliding calliper was used to measure the distance between the medial and lateral epicondyles of the humerus, starting proximately to the sites. The bony points first felt were the epicondyles, and then strong pressure was applied until the value was read. Because the medial epicondyle is normally lower than the lateral epicondyle, the measured distance may be somewhat oblique.

The kinanthropometric profile gives an indication of the body type, which may influence the ability to throw a ball, as well as the amount of weight behind the throw. Limb length could influence the amount of momentum generated during the throwing action and thus determined the distance that a ball is thrown.
E. STATISTICAL ANALYSIS

The Department of Statistics and Mathematics at Stellenbosch University undertook the statistical analysis. The correlation used to determine the results was the Spearman rank-order correlation. All the variables were compared to the distance the ball was thrown, both when seated on the chair and strapped in while sitting on the chair. A comparison was also made using the weight of the subject, while comparing all other values. Subsequently r and p values with the standard deviations were determined. The analysis was done making use of Statistica. The significance level used was p=0.05.
CHAPTER FOUR

RESULTS

A. INTRODUCTION

Throwing athletes display a number of similar characteristics, such as increased external rotation and decrease in internal rotation of the shoulder joint, as seen in previous studies (Ciullo, 1996; Jobe & Pink, 1993; Ellenbecker et al., 2002; Bak, 1997; Baltaci, 2001). The question arises as to whether these changes in range of motion could be ascribed to the repetitive throwing of the athletes, or whether the athletes were born with this increased external and a decreased internal rotation. Did the above factors contribute to the athletes’ participation in these overhead sports which would give them a better chance of enhanced throwing performance, or was it merely superior technique that caused them to throw in this superior manner?

The focus of this study was to assess selected physical factors that contributed to efficient throwing ability of the athlete. The aim was to determine to what extent these factors contributed and how important they were in the performance of the throwing athlete. It was decided to use the average of the throwing distances and not the maximal distance achieved by the athlete. The reason for this was that during a game the athlete is required to do repetitive throwing motions and not only one where the best result is then recorded. Thus it is more game specific using the average rather than the maximum throw.

In this study the intra-personal variation was not a factor. There was one cricket player with high variations which was excluded from the study, but in general the variation did not influence the overall results, it was very constant.
B. CRICKET

When comparing throwing distance with the various independent variables that were tested, it was found that there were not many statistically significant relationships.

1. Limb length

To determine the limb length the arm was divided up into three parts, namely the part between the acromiale and the radiale landmarks, then from the radiale to the mid-styliion landmark, and then from the mid-styliion to the dactylion landmark. These distances were then measured separately, so that one could calculate the contribution of each part of the arm. There was no significant correlation with any one of these lengths when comparing it to the average distance that was thrown while the athletes were strapped in.

![Graph showing limb length and average throwing distance of cricket players](image)

Figure 4.1: Limb length and the average of the distance thrown of cricket players.
2. Core stability

Both the core stability tests – which consisted of the one minute swissball walkout and the leg drop test with the stability cuff – had no significant correlation with the distance thrown by the athlete. Negative correlation was found between the one minute swissball walkout and the throwing for distance when seated ($r= -0.46; p=0.13$), and also when strapped in and throwing for distance ($r=-0.10; p=0.93$), but both not statistically significant. The other stability test that was done, namely the leg drop test, compared to throwing for distance ($r=0.26; p=0.30$), showed a weak positive correlation. When strapped in throwing for distance ($r=-0.31; p=0.22$), there was found to be a weak negative correlation, but both not statistical significant.

![Figure 4.2: Number of swissball roll-outs to average distance thrown by the cricket players.](image-url)
Figure 4.3: Amount of leg drops to average throwing distance of cricket players.

3. Range of motion

There was a considerable range of motion measurements that were computed, but none of them correlated significantly with the distance thrown by the cricket players. There was various negative correlation with throwing strapped in, namely supination ($r=-0.28; p=0.48$), pronation ($r=-0.55; p=0.10$), lateral flexion to the right ($r=-0.14; p=0.75$) and lateral flexion to the left ($r=-0.26; 0.72$), but no statistically significant correlation was found. Some more weak negative correlations that were found with the subjects strapped in and throwing, was with the supination ($r=-0.24; p=0.59$), pronation ($r=-0.47; p=0.22$), elbow extension ($r=-0.01; p=0.65$), lateral flexion to the right ($r=-0.24; p=0.93$), lateral flexion to the left ($r=-0.27; p=0.77$) and wrist flexion ($r=-0.08; p=0.69$), but again no statistical significance was found. There is a tendency towards a significantly positive relationship with the internal rotation when the subject was seated on the chair without being strapped in ($r=0.35; p=0.04$).
4. Isokinetic testing

Peak torque

The peak torque was generated at 90 and 180°/seconds; using both concentric/concentric as well as concentric/eccentric contractions. There was a much better correlation with the throwing for distance seated on the chair, than throwing when strapped in. The peak torque concentric/concentric at 90°/second during external rotation (r= 0.61, p=0.06) and the peak torque concentric/concentric at 90°/second during internal rotation (r= 0.49, p=0.06), both tend to a correlation but are not statistically significant. There was a positive significant correlation with the peak torque concentric/concentric at 180°/second during external rotation (r= 0.45, p=0.04) when the subject was strapped in.

Peak torque/Body weight (%)

To consider the size of the subject, the peak torque measurement was taken and together with the body weight a percentage was determined. None of these scores had a significant correlation with the thrower strapped in, as well as when seated while throwing for distance.

Average power (watts)

The average power measured in watts generated at both 90 and 180°/second as well as concentric/concentric and concentric/eccentric contractions proved to provide generally a higher correlation with various significant correlations in both throwing for distance seated and throwing for distance strapped in. The following was all found to be positive and statistical significant factors the average power concentric/concentric contractions at 90°/second during external rotation when seated on chair(r= 0.64 and p=0.03) and average power concentric/concentric contractions at 180°/second during external rotation when seated on chair (r= 0.57 and p=0.01), the
average power concentric/eccentric $90^\circ$/second internal rotation both when seated on chair ($r=0.58; p=0.04$) as well as strapped in on chair ($r=0.60; p=0.03$). All these correlations were positive although only a few statistically significant.

**Average peak torque (Nm)**

The average peak torque was measured in nanometres (Nm) and was measured at 90 and $180^\circ$/second with both concentric/concentric and concentric/eccentric contractions. There was a significant correlation which was positive with the average peak torque concentric/concentric 180 degrees/second with external rotation seated on the chair ($r=0.46; 0.03$). There was also a tendency towards a significant correlation when the subject was seated in average peak torque concentric/concentric at $90^\circ$/second both with internal ($r=0.52; p=0.06$) and external rotation ($r=0.62; p=0.05$). For the remainder of the average peak torque measurements no correlation was found.

**Agonist/Atagonist ratio (%)**

The agonist/antagonist ratio was expressed as a percentage. These measurements had a very weak correlation with the throwing for distance, both seated and strapped in.

**5. Anthropometric measurements**

Table 4.1. provides a summary of the anthropometric measurements of the cricket subjects.
6. General information on subjects

Table 4.1: Anthropometric measures of the cricket players

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Height</td>
<td>1.82 m</td>
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</tr>
<tr>
<td>Weight</td>
<td>81.10 kg</td>
<td>7.94</td>
</tr>
<tr>
<td>Arm span</td>
<td>1.86 m</td>
<td>0.07</td>
</tr>
<tr>
<td>Fat percentage</td>
<td>13.26 %</td>
<td>8.90 %</td>
</tr>
<tr>
<td>Bi-acromion width</td>
<td>40.20 cm</td>
<td>1.79</td>
</tr>
<tr>
<td>Bi-epicondyle width</td>
<td>7.10 cm</td>
<td>0.52</td>
</tr>
<tr>
<td>Relaxed bicep circumference</td>
<td>31.40 cm</td>
<td>1.80</td>
</tr>
<tr>
<td>Tense bicep circumference</td>
<td>34.95 cm</td>
<td>1.63</td>
</tr>
<tr>
<td>Forearm circumference</td>
<td>29.65 cm</td>
<td>0.81</td>
</tr>
<tr>
<td>Chest circumference</td>
<td>98.00 cm</td>
<td>3.39</td>
</tr>
<tr>
<td>Waist circumference</td>
<td>82.00 cm</td>
<td>4.34</td>
</tr>
<tr>
<td>Gluteal circumference</td>
<td>103.65 cm</td>
<td>5.16</td>
</tr>
</tbody>
</table>

6.1 Age

The average age of the cricket players was 21.7 ± 2.64 years. This age is typical for club level players, in other words the young adult group of players.

6.2 Stature and weight

The cricket players displayed an average height of 1.81 ± 0.05 metres and a weight of 80.82 ± 7.94 kilograms.
### Table 4.2: Profile of the cricket and netball players

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Body mass</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cricket subjects</td>
<td>21.7±2.64years</td>
<td>69.57±8.88kg</td>
<td>1.73±0.06m</td>
</tr>
<tr>
<td>Netball subjects</td>
<td>19.75±1.22years</td>
<td>81.1±7.94kg</td>
<td>1.82±0.05m</td>
</tr>
</tbody>
</table>

### C. NETBALL

When comparing the throwing for distance to the different variables that were tested it was found that not many variables were statistically significant.

#### 1. Limb length

As with the cricket men, the arm was divided up into three parts, namely the acromiale to the radiale, then from the radiale to the mid-stylion, and then from the mid-stylion to the dactylion. There was a very weak correlation between all of these measurements and both throwing for distance seated and strapped in.
2. Core stability

The core stability tests conducted were the one-minute swissball walkout and the leg drop with the stability cuff. In both these tests there was an insignificant correlation of both the throwing for distance seated (r= -0.03; p=0.82 and r=0.08; p=0.82) respectively) and strapped in (r= 0.08; p=0.76 and r=0.20; p=0.46) respectively.

Figure 4.5: Amount of swissball roll-outs to average distance thrown by the netball players.
3. Range of motion

Various ranges of motion measurements were undertaken. Comparing these measurements to those relating to throwing for distance, there was no significant correlation found either.

4. Isokinetic testing

4.1. Peak torque

The peak torque of the subject was measured doing abducted internal external rotation at both 90 and 180°/second and concentric/concentric as well as concentric/eccentric contractions. The measurements that correlated with the thrower strapped in, were peak torque concentric/concentric contraction at 180°/second during external rotation (r= 0.44; p=0.02) The other peak torque measurements had a weak correlation with both throwing for distance when strapped in, as well as throwing for distance when seated.
4.2. **Peak torque/Body weight (%)**

To place this measurement more into perspective, the weight of the subject was divided by the peak torque of the subject and then expressed as a percentage. In all of these measurements there was no significant difference when comparing to the distance thrown but they all had a negative correlation related to peak torque/body weight, seated and throwing as well as strapped in and throwing.

4.3. **Average power (watts)**

The average power output of the subjects during the abducted internal external rotation was measured in watts. All the scores obtained during this testing were non-significant and, therefore, no correlations were found.

4.4. **Average peak torque (Nm)**

The average peak torque of the testing was measured in nanometres (Nm). Again the measurements had no significant correlation with the throwing for distance, both seated and strapped in.

4.5. **Agonist/Atagonist ratio (%)**

The ratio of the internal rotators compared to the external rotators was assigned a percentage value. All the measurements had a non-significant correlation.
5. **Anthropometric measurements**

Table 4.3 provides a summary of the anthropometric data of the netball players.

Table 4.3: Anthropometric data of the netball players tested

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Median</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>1.73 m</td>
<td>1.73 m</td>
<td>0.06</td>
<td>1.61 m</td>
<td>1.86 m</td>
</tr>
<tr>
<td>Weight</td>
<td>69.57 kg</td>
<td>69.95 kg</td>
<td>8.88</td>
<td>50.80 kg</td>
<td>89.60 kg</td>
</tr>
<tr>
<td>Arm span</td>
<td>1.75 m</td>
<td>1.74 m</td>
<td>0.08</td>
<td>1.61 m</td>
<td>1.90 m</td>
</tr>
<tr>
<td>Fat percentage</td>
<td>23.52 %</td>
<td>23.86 %</td>
<td>4.53</td>
<td>13.41 %</td>
<td>30.28 %</td>
</tr>
<tr>
<td>Bi-acromion width</td>
<td>38.31 cm</td>
<td>38.15 cm</td>
<td>1.37</td>
<td>35.70 cm</td>
<td>40.90 cm</td>
</tr>
<tr>
<td>Bi-epicondyle width</td>
<td>6.29 cm</td>
<td>6.30 cm</td>
<td>0.30</td>
<td>5.70 cm</td>
<td>6.90 cm</td>
</tr>
<tr>
<td>Relaxed bicep circumference</td>
<td>28.20 cm</td>
<td>28.55 cm</td>
<td>2.16</td>
<td>21.30 cm</td>
<td>31.20 cm</td>
</tr>
<tr>
<td>Tense bicep circumference</td>
<td>29.60 cm</td>
<td>29.75 cm</td>
<td>2.04</td>
<td>24.50 cm</td>
<td>33.60 cm</td>
</tr>
<tr>
<td>Forearm circumference</td>
<td>25.98 cm</td>
<td>26.30 cm</td>
<td>1.41</td>
<td>22.10 cm</td>
<td>28.40 cm</td>
</tr>
<tr>
<td>Chest circumference</td>
<td>90.58 cm</td>
<td>90.70 cm</td>
<td>4.25</td>
<td>81.20 cm</td>
<td>98.90 cm</td>
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<tr>
<td>Waist circumference</td>
<td>74.30 cm</td>
<td>74.00 cm</td>
<td>5.16</td>
<td>65.60 cm</td>
<td>84.00 cm</td>
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<tr>
<td>Gluteal circumference</td>
<td>103.72 cm</td>
<td>104.05 cm</td>
<td>6.25</td>
<td>91.40 cm</td>
<td>118.00 cm</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

DISCUSSION

According to Cohen et al (1994), the ultimate performance of any complex chain of torque transfers depends on several factors including technique, muscular strength and flexibility of the athlete. In the study done on tennis players, they analysed some of these factors. Factors that related to the serve velocity was flexibility measures, including dominant wrist flexion (p<0.01), dominant shoulder forward flexion (p<0.05), and dominant shoulder internal rotation at 0° of abduction (p=0.06). In our study there was no correlation with wrist flexion, not with the netball players or the cricket players. In Cohen’s study (1994) it was also found that muscular strength related to the serve velocity namely, extension torque production and the ratio of internal to external rotation torque production (p<0.05). No correlation was found in this study. There was also a relationship between the speed and elbow extension torque (p<0.01) in tennis players (Cohen et al, 1994). This finding was similar to the study by Pedegana et al. (1982) who tested baseball pitchers. In the study by Pedegana et al. (1982) there was a positive correlation between the strength of certain upper extremity muscle groups and the throwing speed of the subject. It was also found that the elbow extension had an relationship with the throwing speed (Pedegana et al, 1982).

Clements et al. (2001a) did a study on adolescents where the upper limb musculoskeletal profile and throwing speed in adolescent baseball players were tested compared to matched controls. There was no significant difference found between baseball and control groups for shoulder internal and external rotation, elbow flexion and extension or forearm supination range of motion. In our study the cricket players showed a significant relationship between the internal rotation range of motion compared to the distance thrown (r=0.35; p=0.04). The forearm pronation range of motion was found to be significantly greater in baseball players than in the control subjects (p=0.03), which was not true in our study. It was also found that there was a
significant effect between groups when combining the movements of internal rotation, elbow extension and pronation (p=0.02), all associated with ball release and follow through. The peak torques between the baseball group and the control group showed no significant difference between the two groups. There was a significant difference in the overhead throwing speed, being faster for the baseball players compared to the control group (p<0.001) (Clements et al., 2001a).

In another study done by Clements et al. (2001b), the aim of the study was to determine if upper body limb muscle strength correlates with throwing speed in adolescent baseball players. It was found that isometric shoulder internal rotation and concentric elbow extension peak torque-to-body-weight ratios demonstrated significant correlation with throwing speed (p<0.01) In this study there was no correlation at all with the peak torque to body weight, not in any of the groups. Concentric shoulder internal rotation peak torque-to-body weight also correlated moderately, but not significantly with throwing speed (Clements et al., 2001a). As seen previously, this agrees with the study done by Pedegana et al. (1982) which showed that elbow extension peak torque can be seen as a predictor of throwing speed.

Bartlett et al. (1989) did a study to establish whether or not a correlation exists between peak torque production of upper extremities musculature and throwing speed. The results of this study showed that there was a strong positive correlation between the peak torque production of the dominant arm’s shoulder adduction and throwing speed (p=0.04). There was a definite trend towards significance exhibited in dominant arm shoulder extensors and the throwing speed (p=0.08). In this current study there was a few significant correlations with peak torque compared to the throwing for distance, but it did not correlate with these found by Bartlett et al. (1989) The internal and external rotation as tested in our study had no significance.

When comparing our study to the one of Bayios et al. (2001), it can be seen that there was a difference in the results found. The aim of the study by Bayios et al. (2001) 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. Although in our study we did not test the ball velocity, but the distance thrown, a relationship between the two can be drawn.

It is not always certain if the increase range of motion found in a lot of studies done on overhead atletes is caused by the repetitive movements, or is it a natural increase in range of motion that causes them to be good players. In the study by Brown et al. (1988) this finding was shown to be due to adaptation. There was no significant difference in the external rotation in the neutral position comparing the dominant and the non dominant sides, but there was a difference of significance in the abducted position comparing the two sides. This tells us that it is adapted due to the throwing motion done in an abducted fashion.

Table 5.1.: Comparison to a previous study

<table>
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<tbody>
<tr>
<td></td>
<td>Tennis</td>
<td>Netball</td>
<td>Cricket</td>
</tr>
<tr>
<td>Wrist flexion</td>
<td>78.7</td>
<td>81</td>
<td>83</td>
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<tr>
<td>Wrist extension</td>
<td>67.5</td>
<td>65.5</td>
<td>64</td>
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<tr>
<td>Pronation</td>
<td>74.7</td>
<td>85</td>
<td>76</td>
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<tr>
<td>Supination</td>
<td>82.9</td>
<td>85</td>
<td>76</td>
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<tr>
<td>Elbow flexion</td>
<td>142.3</td>
<td>151</td>
<td>146</td>
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<tr>
<td>Elbow extension</td>
<td>0.5</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>IR 95° abduction</td>
<td>61.5</td>
<td>36.5</td>
<td>35</td>
</tr>
<tr>
<td>ER 95° abduction</td>
<td>101.3</td>
<td>90</td>
<td>96</td>
</tr>
<tr>
<td>Side flexion right</td>
<td>Not tested</td>
<td>40.5</td>
<td>45</td>
</tr>
<tr>
<td>Side flexion left</td>
<td>Not tested</td>
<td>42</td>
<td>46</td>
</tr>
</tbody>
</table>

When scrutinising the comparison of the studies, it could be deduced that in general the range of motion was more or less the same. There was a decrease in internal
rotation at 90° of abduction in both the netball and the cricket players. When comparing these measurements to those of the tennis players, a decrease in the external rotation at 90° of abduction was seen. But as seen, none of the factors of significance are the same in the studies.

SUMMARY OF THE FINDINGS

1. Limb length

One would have expected that there would be a correlation between the distance that athletes throw and the length of their limbs, because of the momentum that is brought about with a greater lever length. The greater the length of a lever, the greater the linear displacement is of that lever, including the velocity and the acceleration that occur at the end point of the lever (Luttgens & Hamilton, 1997).

After this said, there was no significant correlation found between the limb length and the distance that was thrown, both seated and strapped in. This can give us an indication that the momentum build up does not exist in the arm, but can be due to the kinetic chain, and the arm is mere a part that the energy build-up moves through.

2. Core Stability

This term has been a buzzword lately and the relevant types of exercises are increasingly incorporated into all training programmes. The core stability tests tested different types of core stability, namely local and global core stability. It was expected that the global stabilisers would have a significantly positive correlation to the distance with which the athlete throws, which would have meant that the energy
transfer should be more effective. But amongst both the netball and the cricket players there was no significant relationship. It could thus be said that the core stability did not play a significant role in distance achieved by these subjects. We can say the energy transfer passes through the core muscles and thus they need not generate the energy or be strong for the energy transfer to take place. Again we can refer to the kinetic chain with the transfer of the energy from the lower limbs, the upper limbs and energy transfer that takes place, regardless of the state of the core stabilisers. One could state that there is a possibility that the core stability may play a role in preventing injuries and not necessarily in the transfer of energy, or in the enhancement of the performance of the athlete, but have other functions.

3. Range of motion

In many studies done, which included range of motion, an increase in the external and decrease in the internal rotation were found. There is a great deal of controversy around this subject whether the difference in range of motion is caused by the repetitive throwing, or whether it is the range of motion difference that causes the athlete to be successful, because $v=s/t$, where $v$ is the velocity, $s$=distance, and $t$=time (Luttgens & Hamilton, 1997). Thus the further the range is that the ball is travelling before leaving your hand, the higher the velocity and thus the further the ball is thrown. Consequently, if there is an increase in range of motion, the distance the ball is travelling could be expected to be further. The results obtained among the netball players were that there was no measurement done that showed a significant correlation with the distance thrown. This could be because the distance and the velocity with which netball players throw, are not necessarily very influential in the range of motion that it causes in terms of an increase or a decrease in the range of motion. Most of the previous studies done on the range of motion of athletes using overhead throwing actions were on baseball pitchers, who use a very dynamic motion, which causes a great deal of tension. The cricket players displayed a significant positive correlation with the internal rotation ($p=0.04; r=0.35$) when the subjects was
seated on the chair. But no other range of motion measurements had significant correlations.

4. Isokinetic data

4.1. Peak torque

The reason for the increased peak torque when the athletes are merely seated and the decrease when the athletes are seated and strapped in, relates to the upper body. Athletes can normally use the upper body to generate energy and eventually transfer the energy to the ball.

The only significant correlation found amongst the netball players were the peak torque concentric/concentric contraction at 180°/second during external rotation, and strapped in (p=0.02; r=0.44). With the cricket players there were more correlations that were rather weak but positive and showed a tendency towards significance. Those were the concentric/concentric contraction seated at 90°/second ER (p=0.06; r=0.61), seated at 90° IR (p=0.06; r=0.49), seated at 180° ER (p=0.04; r=0.45) and also the concentric/eccentric 90°/second IR strapped in (p=0.04; r=-0.47), which showed an negative correlation.

With the cricket players it was evident that the energy generated in the torso was important, and not merely the torque generated in the shoulder joint. This was again emphasised in the kinetic chain and the energy that transferred from the lower extremities. The peak torque of the netball players had a very weak correlation and it may be ascribed to the seated position from which the athletes were throwing, and the generated force transferred by the kinetic chain, which was decreased because of the limited amount of body segments available for the generation of force.
4.2. Peak torque to body weight

There was no correlation or difference between cricket players’ throwing for distance when the athletes were strapped in and not strapped in. This is especially true when body weight is considered. This could be attributed to the fact that the more weight there is “behind” the throw, the more momentum can be generated. Consequently, there is an increase in the speed or the distance that the ball can possibly be thrown. There was a very weak negative correlation between the percentage peak torque to body weight and the distance that the athletes could throw. Thus, the heavier the athletes, the further they were able to throw. One could then conclude that in terms of netball players, the weight behind the players could play a small, but not significant role in the distance that the ball can be thrown.

4.3. Average power

The rate at which work is done is defined as power (P) and can be expressed as work (W) over time (t), \( P = \frac{W}{t} \) where the work done, is the force (F) times the distance (s) along which the force was applied (\( W = Fs \)). There was a positive statistical significant correlation between the time, the work performed and the distance that the ball travelled. Among cricket players this was evident that the quicker they generated the force over the specified distance, the further the ball would travel. Most of the values for the seated throw there was a significant correlation or tendency towards a positive significant correlation. On the other hand there were no significant correlations with the netball players to verify that there was a correlation between the power generated in the athletes’ shoulder and the distance that the ball travelled after release. This may be because the netball players do not throw the ball the same distances as the cricket players do, and thus the power needed to release the ball is not as large as the power generated by the cricket players.
4.4. Average peak torque

Torque is the product of the force that exists and the length of the moment arm. Thus a change in the force or a change in the length of the moment arm, may cause a change in the torque. The peak torque was the highest degree of torque generated throughout the test that was conducted. For the cricket players all the concentric/concentric throwing seated was all tending to a positive significant correlation. But the netball players did not show any significant correlations.

4.5. Agonist/antagonist ratio

The ratio did not play a significant role in the netball or in the cricket players compared to the throwing for distance. There was no correlation at all. Thus it could be said that in terms of throwing further, the ratio of the internal and external rotators would not play a role. This may influence the injury prevention but has no influence on the distance that the athlete will throw.
CHAPTER SIX

CONCLUSION

As previously stated, it is important for athletes to be able to throw the ball accurately and with enough power from the one point to the next. In the case of this study we did not look at the accuracy of the throw, but rather at the distance reached with the throw. Because of various factors like ball size, court size, ball weight and the nature of the sport, there are differences in the throwing action of the cricket and netball players. Fundamentally, the physical factors tested may affect the power in both the netball and the cricket players in some way, because the basic execution stays the same (Luttgens & Hamilton, 1997).

The main focus of this study was to determine the physical factors that correlated with the performance in throwing amongst club level cricket and netball players. Before addressing this matter several other questions first had to be addressed.

The first question would be whether a throwing athlete does need a strong core to be able to perform the throwing motion optimally and to transfer energy. When scrutinising the results obtained in terms of core stability, none of the tests correlated significantly with the distance that was thrown. Thus one cannot state that core stability plays a role in the distance that an athlete throws, or that it is an essential part of the physical factors responsible for an efficient throw. The core stability may have other functions during the throwing actions as to transfer energy and in injury prevention.

The second question that arose was that, if a netball or cricket player displayed an increase in range of motion, would this lead to an increase in power relating to the distance that the athlete is able to throw? It was found that the only statistical significant relationship was in the cricket players where the internal rotation range of motion had a positive correlation with the distance thrown when the athlete was seated but not strapped in. For the other measurements taken there were no
significant correlations with the distance that the netball or the cricket players were able to throw.

The third question to be answered was to determine whether the limb length of the throwing athlete played a role in the distance thrown or the power generated. Again no statistically significant correlation was found with any of the measurements done.

The fourth question to be answered was to determine if there was a relationship between the isokinetic testing done and the distance that the athlete was able to throw. We saw that there was various isokinetic results in the cricket players that contributed to an increase in the distance the athlete was able to throw. Most of these correlated with the seated on the chair, and not strapped in. We can thus say that there might be a relationship between the isokinetic strength in the cricket players specially the peak torque and the average power as well as the average peak torque.

The next question that arises is whether physical factors played a role in the throwing action or whether it was purely a question of technique. In the tests done there were several correlations between the selected physical factors and the distance thrown, but these correlations were rather weak and few.

When looking at various studies done, in particular the study by Hirashima et al (2001) the proximal-to-distal segmental sequence is important in throwing. All our testing done for throwing was done in the seated position, eliminating this kinetic chain that is important for the throwing for distance, or just throwing in general.

Altchek and Hobbs (2001) stated that throwing is the transfer of kinetic energy through the legs, hips, spine, shoulder, elbow and wrist. The external oblique contralateral to the throwing arm becomes activated before the ipsi-lateral external oblique. This sequence is considered to be very effective for the generation of high force and energy in the trunk. The ipsilateral external oblique begins its activity almost at foot strike. The main activity of the rectus abdominis appears just before the point of release. (Hirashima et al., 2002). As mentioned, the core is involved as part of the kinetic chain but does not play the largest part.
We founded that, as part of many test protocols for overhead throwing, tests are being done in a seated position as part of the test battery. If it is the kinetic chain that influence the throwing action, a seated test might not be so useful as part of assessments.

An athlete might be a good thrower, but not be able to use his lower limbs in the throwing action, which could have an great influence on his technique and the athlete might even need to change his technique. By only using the muscles of the upper extremities, a shorter kinetic chain is then present with less effective energy transfer.

The purpose of this study was to assess the contribution of selected physical factors to a powerful throw in cricket and netball players. If one physical factor was to be said to be the most important of all, it would be internal external rotational strength. But none of the physical factors had strong enough statistical correlations with the throwing for distance and thus it would appear that technique is the most important factor for throwing for distance.

There was a few limitations in the study that might have influenced the results. The first was that the subjects volunteered to take part in the study and only a limited number of athletes eventually participated in the project. All the athletes who commenced with the project did not complete all tests and therefore the sample size in some instances was small. There was a limitation in the apparatus that was available, thus the speed of the ball could not be measured, as in most studies, thus distance thrown was measured instead. Lastly the anthropometric testing was done before other testing due to logistics of the test battery, which can be seen to have had an influence on the outcome of the skinfold results.

Thus to conclude when an athlete needs to increase the distance that they are able to throw, the focus of the exercise program should rather be on the energy transfer and the technique of the throw rather than getting into the gym and increasing the athletes flexibility, strength or power, and core stability. These factors may contribute in other areas of the play and shouldn’t be neglected, but for the focus of this study the suggestion of the kinetic chain starting at the toes should be addressed.
REFERENCES


BAYIOS, I.A.; ANASTASOPOULOU, E.M.; SIOUDRIS, D.S. & BOUDLOLOS, K.D. (2001). Relationship between isokinetic strength of the internal and external shoulder...


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http://www.sasportdata.co.za/rules/cricket/field_settingl.gif
APPENDIX A
QUETIONNAIRE

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<th>Date: __________________________</th>
<th>Dominant side: R L</th>
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<tr>
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</tr>
<tr>
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<td>D.O.B: __________</td>
</tr>
<tr>
<td>Contact no.: __________________</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>Years of participating: ___________________________</td>
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<td>Exercise regiments: Activity Time/week Duration</td>
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</tr>
<tr>
<td>Injury: Year/Month: ________________</td>
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<tr>
<td>Specify: ___________________________</td>
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</tr>
<tr>
<td>Involved side: R L Treatment received: __________________</td>
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<tr>
<td>Onset: Trauma Gradual Other ________</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Contra-insications to exercise: Yes No ___________________</td>
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<td>Other orthopaedic problems: Yes No ___________________</td>
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# APPENDIX B

## PHYSICAL EVALUATION

Subject ______________________________________________________________

<table>
<thead>
<tr>
<th>Height _____ m</th>
<th>Weight _____ kg</th>
<th>“Wing span” _____ cm</th>
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</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Median</td>
</tr>
</tbody>
</table>

### Acromiale

### Radiale

### Mid acromiale-radiale

### Stylion

### Subscapulare

### Supraspinale

### Abdominal

### SKINFOLDS

- Chest  ↑  Abdominal  ↓
- Suprailium  ↑  Subscapular  ↓
- Triceps  ↑  ↓

### LENGTHS

- Acromiale-radiale
- Radiale-stylion
- Midstylion-dactylium

### BREATHS

- Biacromiale
- Bi-epicondylar humerus

### CIRCUMFERENCES

- Biceps relaxed
- Biceps tense
- Fore arm
- Chest
- Waist
- Gluteal

### SCAPULAR MOVEMENTS

- Arms relaxed  Right  Left
- Hands on hips
- @ 90° with max IR

### LAXITY TEST

- -130-
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<thead>
<tr>
<th>Ant. Drawer</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior Drawer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ROM**

<table>
<thead>
<tr>
<th>Posterior acromion process</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral epicondyle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olecranon process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulnar styliion process</td>
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<td></td>
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<tr>
<td>Total body rotation</td>
<td></td>
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</tr>
<tr>
<td>Shoulder internal rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder external rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow extension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm pronation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm supination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist extension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine lateral flexion right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine lateral flexion left</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine flexion C7 to T12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine flexion C7 to S1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ISOKINETIC TESTING**

| 60 deg/sec con/con       |       |       |
| 180 deg/sec con/con      |       |       |
| 60 deg/sec con/ecc       |       |       |
| 180 deg/sec con/ecc      |       |       |

**THROWING FOR DISTANCE**

| Strapped in |       |       |
| Seated      |       |       |

**STABILITY TESTS**

| Leg drop in 1 min |       |       |
| Swiss ball forward and back |       |       |
APPENDIX C

CONSENT FORM

Athlete’s name: ________________________  Date of Birth: ______________
Sport: ________________________________  Tel: _______________________

Please read the following carefully:

1. You were invited to participate in a project that is hosted by the Department of Sport science at the University of Stellenbosch
2. No invasive procedures or drugs would be given for testing purposes
3. For the success of this project it is important that you give your full cooperation, and give your best attempts regarding the testing
4. There will be no cost involved for you in participating in this project
5. It was explained to me that I will partake in fitness tests as well as body composition and analysis tests
6. The testing procedures have been explained to me by the test administrators and I understand them
7. I was given the opportunity to ask questions and that all my questions was answered satisfactory

Here by I, _________________________________ (name and surname) declare that
  • I understand what the aim of this project is
  • I participate voluntary
  • I give my consent that the data obtained may be used for research purposes
  • I set the University of Stellenbosch and all the testing persons free of responsibility of injury or damage that may be caused by participating in this project

I hereby voluntarily take part in the above-mentioned project

__________________________________  ________________________
signed        date

__________________________________
witness
### APPENDIX D

**STATISTICAL DATA**

Table 6.1. Reporting the r and p values in the distance thrown while seated on chair and while seated on the chair and strapped with regards to various physical factors in the Netball players

<table>
<thead>
<tr>
<th>Strapped in</th>
<th>Seated throwing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
</tr>
<tr>
<td>Acromiale-radiale</td>
<td>0.22</td>
</tr>
<tr>
<td>Radiale-stylion</td>
<td>0.14</td>
</tr>
<tr>
<td>Midstylion-dactylion</td>
<td>0.03</td>
</tr>
<tr>
<td>Leg drop in 1 min</td>
<td>0.08</td>
</tr>
<tr>
<td>1 min swissball roll out</td>
<td>0.20</td>
</tr>
<tr>
<td>ROM internal rotation</td>
<td>-0.22</td>
</tr>
<tr>
<td>ROM external rotation</td>
<td>-0.19</td>
</tr>
<tr>
<td>ROM supination</td>
<td>0.11</td>
</tr>
<tr>
<td>ROM pronation</td>
<td>-0.07</td>
</tr>
<tr>
<td>ROM elbow flexion</td>
<td>0.28</td>
</tr>
<tr>
<td>ROM elbow extension</td>
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</tr>
<tr>
<td>ROM lateral flexion to the right</td>
<td>0.05</td>
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<tr>
<td>ROM lateral flexion to the left</td>
<td>0.25</td>
</tr>
<tr>
<td>ROM wrist flexion</td>
<td>0.17</td>
</tr>
<tr>
<td>ROM wrist extension</td>
<td>0.10</td>
</tr>
<tr>
<td>PT con/con 90 deg/sec ER</td>
<td>0.36</td>
</tr>
<tr>
<td>PT con/con 90 deg/sec IR</td>
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</tr>
<tr>
<td>PT con/con 180 deg/sec ER</td>
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</tr>
<tr>
<td>PT con/con 180 deg/sec IR</td>
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</tr>
<tr>
<td>PT con/ ecc 90 deg/sec ER</td>
<td>0.01</td>
</tr>
<tr>
<td>PT con/ ecc 90 deg/sec IR</td>
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</tr>
<tr>
<td>PT con/ ecc 180 deg/sec ER</td>
<td>-0.03</td>
</tr>
<tr>
<td>PT con/ ecc 180 deg/sec IR</td>
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<tr>
<td>PT/BW (%) con/con 90 deg/sec ER</td>
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</tr>
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<td>PT/BW (%) con/con 90 deg/sec IR</td>
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<tr>
<td>PT/BW (%) con/con 180 deg/sec ER</td>
<td>-0.18</td>
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<tr>
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<tr>
<td>PT/BW (%) con/ ecc 90 deg/sec ER</td>
<td>-0.31</td>
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<tr>
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</tr>
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<td>PT/BW (%) con/ ecc 180 deg/sec ER</td>
<td>-0.31</td>
</tr>
<tr>
<td>PT/BW (%) con/ ecc 180 deg/sec IR</td>
<td>-0.28</td>
</tr>
<tr>
<td>Avg power (watts) con/con 90 deg/sec ER</td>
<td>0.24</td>
</tr>
<tr>
<td>Avg power (watts) con/con 90 deg/sec IR</td>
<td>-0.03</td>
</tr>
<tr>
<td>Avg power (watts) con/con 180 deg/sec ER</td>
<td>0.24</td>
</tr>
<tr>
<td>Avg power (watts) con/con 180 deg/sec IR</td>
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</tr>
<tr>
<td>Avg power (watts) con/ ecc 90 deg/sec ER</td>
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<td>-------------</td>
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<td>0.37</td>
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<td>Leg drop in 1 min</td>
<td>0.26</td>
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<tr>
<td>1 min swissball roll out</td>
<td>-0.10</td>
</tr>
<tr>
<td>ROM internal rotation</td>
<td>0.26</td>
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<td>ROM external rotation</td>
<td>0.10</td>
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<tr>
<td>ROM supination</td>
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<td>ROM pronation</td>
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<tr>
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<td>ROM elbow extension</td>
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<td>ROM lateral flexion to the right</td>
<td>-0.14</td>
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<td>0.17</td>
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<td>PT/BW (%) con/ ecc 90deg/sec IR</td>
<td>-0.16</td>
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</tbody>
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Table 6.2. Reporting the r and p values in the distance thrown while seated on chair and while seated on the chair and strapped with regards to various physical factors in the Cricket players.
<table>
<thead>
<tr>
<th></th>
<th>con/ecc 180 deg/sec ER</th>
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<td>0.42</td>
<td>0.33</td>
<td>0.23</td>
</tr>
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<td>0.64</td>
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<tr>
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<td>Avg power (watts)</td>
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<td>0.57</td>
<td>0.01</td>
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<tr>
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<td>0.24</td>
</tr>
<tr>
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<td>0.03</td>
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<tr>
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<tr>
<td>Avg PT (Nm)</td>
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<td>0.62</td>
<td>0.05</td>
</tr>
<tr>
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<td>0.94</td>
<td>0.52</td>
<td>0.06</td>
</tr>
<tr>
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<td>0.43</td>
<td>0.46</td>
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<tr>
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<td>-0.03</td>
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<tr>
<td>Avg PT (Nm)</td>
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<td>0.45</td>
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<tr>
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<td>-0.24</td>
<td>0.13</td>
<td>0.11</td>
<td>0.95</td>
</tr>
<tr>
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<td>0.44</td>
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<tr>
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<td>0.21</td>
<td>0.54</td>
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</table>

PT = Peak Torque; BW = Body weight; con = concentric; ecc = eccentric; deg = degrees; sec = second; IR = internal rotation; ER = external rotation