# THE INFLUENCE OF MUSCULOSKELETAL VARIABLES ON THROWING PERFORMANCE IN AMATEUR AND ELITE SOUTH AFRICAN CRICKETERS

By

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## DECLARATION

I, Safwaan Ahmed, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor part of it has been, is being, or is to be submitted for another degree in this or any other university.



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# THESIS ABSTRACT

The game of cricket consists of batting, bowling and fielding. Each of these disciplines require different skills and physical capabilities. The literature exploring these disciplines have traditionally focused on batting and bowling with little research on fielding. However, the increase in popularity of the T20 cricket format has highlighted the importance of optimal fielding performance on the outcome of the game. Efficient fielding requires timely ball retrieval and a well-executed return-throw with the aim of dismissing a batsman or reducing the run rate. The novelty in this research lies in its meaningful contribution in identifying and understanding the musculoskeletal factors that contribute to optimal throwing performance specifically in cricket fielding. These factors may help in the development of an exercise intervention aimed at improving throwing performance in cricketers. The aim of this thesis was to determine and understand the influence of musculoskeletal variables on throwing performance in cricketers. Further it was to compare the musculoskeletal profile between amateur and elite cricketers and to investigate if the factors that contribute to throwing performance were different between the two groups

Optimal throwing performance (speed and accuracy) is built on a complex interaction of multiple physical and visuomotor variables. An overview of the literature (Chapter 2) describes the multi-faceted contribution of a range of variables to throwing performance. It includes the contributions and interactions of both the musculoskeletal system and throwing biomechanics to throwing performance. It further compares the musculoskeletal and biomechanical profile of a cricketer to a baseballer and other throwers, as well as compares differences between amateur and elite throwers in relation to throwing performance. While baseballers have been described as superior throwers to cricketers, it is important to understand that the factors that make up optimal performance between the populations are different. Cricketers appear to have a different musculoskeletal profile compared to other throwers such as baseball pitchers. For example, cricketers do not demonstrate an increased shoulder external rotation gain as

demonstrated by many throwers and have a markedly reduced shoulder rotational strength and hip strength compared to baseball players, amongst other factors. Biomechanically, cricketers tend to throw with a more side arm position with less shoulder external rotation which has been found to be an inferior position compared to an overhead throwing technique when considering both velocity and accuracy. In addition, playing experience and workload within the same sport may also influence the contributors to performance. Cricketers have been shown to have a lower workload threshold with regard to injury risk, compared to baseball, and therefore mismanagement of throwing workloads specific to cricket may have implications on injury risk and subsequently throwing performance. It can therefore be understood that optimal throwing performance is best achieved when training is not only customised to the sport, but to each individual player as well.

The thesis includes two original papers. The first research paper describes the association between musculoskeletal variables and a throwing performance test to evaluate amateur cricketers. Throwing performance included ball velocity and a novel throwing accuracy test. The musculoskeletal variables included strength, range of movement, stability tests which have been previously used to investigate overhead athletes in a number of sports, for both injury prevention and performance. The aim of the second paper was to evaluate elite athletes with the same testing battery to identify if there were differences in musculoskeletal profile and throwing performance between cricketers at different playing levels and whether similar musculoskeletal factors accounted for throwing performance for the two groups.

Data collection involved three main steps. First, demographic data, injury history, training experience and a shoulder function questionnaire was completed by participants. Secondly, musculoskeletal testing which included strength measures of the shoulder complex and hip, shoulder range of motion measures, scapula upward rotation positions and an upper-limb endurance test was performed on participants. Lastly, participants completed a throwing performance test which was performed indoors to control for environmental conditions. A maximal throwing speed test (measured with a radar gun) required players to throw over a distance of 20 m, as well as a maximal accuracy test which used a novel target board was performed. To investigate the association between musculoskeletal variables and throwing speed (TS) and accuracy (TA), bivariate analysis and multivariate linear regression analyses was performed for both groups.

Paper 1 documents the association between a range of musculoskeletal variables and throwing performance (TP) in amateur cricketers. Of the 31 musculoskeletal variables, only one variable correlated with TS and one variable with TA. Specifically, hip abduction strength was positively associated with TS (r = 0.38) (p = 0.015): on average, a strength increase of 10 Newtons (N) was associated with an increase in TS of 0.60 km/h (95% CI: 0.12-1.08). Non-dominant pectoralis minor length correlated positively with TA (r = 0.52) (p = 0.004): on average, a one-centimetre increase in the length correlated to an increase, of 0.633 points (95% CI: 0.225 - 1.041).

Paper 2 documents the musculoskeletal variables that were associated with TP in elite cricketers, in addition to musculoskeletal differences between elite and amateur cricketers. Of the 31 musculoskeletal variables only one variable correlated with TS and one with TA in the elite group. Specifically, horizontal adduction range of motion was positively associated with TS (r = 0.38) (p = 0.045), on average, a one-degree increase in shoulder horizontal adduction range of motion was associated with an increase in TS of 0.46 km/h (95% CI: 0.012 - 0.920). Dominant internal rotation strength correlated positively with TA (r = 0.45) (p = 0.019): on average, a strength increase of 10 N was associated with an increase, of 0.34 points (95% CI: 0.06 – 0.62). Throwing speed and TA between groups were not significantly different. Six of the thirty-one musculoskeletal variables measured were found to be significantly different between groups. This signified that firstly, players of different levels may have different musculoskeletal profiles even when playing the same sport. Secondly this highlighted that even while TP had been similar, the variables that were associated with performance were

different. The relationship between musculoskeletal variables and TP was further evaluated for the combined group of cricketers. In a combined group statistic, internal rotation strength ($r = 0.35$) and hip abduction strength ($r = 0.72$) were both positively correlated with TS ($p < 0.05$) while pectoralis minor length was positively correlated with TA ($r = 0.50$) ($p < 0.05$).

In conclusion, from an array of musculoskeletal variables, throwing speed was positively associated with hip abduction strength in the amateur and combined groups, internal rotation strength in the combined group only, and horizontal adduction range of motion in the elite group only. Throwing accuracy was found to be associated with pectoralis minor length in the amateur and combined groups, and internal rotation strength in the elite group only. The musculoskeletal variables linked to TP were different between amateur and elite players. Further, the musculoskeletal profile of cricketers varied between experience levels. This suggests that optimal throwing performance interventions should be based on individual player assessment, or at the very least should be designed to the relevant game and experience level. A future controlled trial should investigate whether an exercise intervention aimed at increasing hip abduction strength in the amateur group, horizontal adduction range in the elite group, and shoulder internal rotation strength in both groups can improve TS; and whether increasing shoulder internal rotation strength in the elite group, and pectoralis minor length in both groups can improve TA.

## CONTRIBUTIONS OF AUTHORS TO THE THESIS

As part of the declaration of this thesis, I acknowledge contributions by various individuals to this work as detailed below:

The experimental design, data collection and analysis for all work were devised by myself, in conjunction with my supervisor Dr Janine Gray.

Dr James brown assisted with all statistical analysis in this thesis.

Assistance for the compilation of the experimental chapters was assisted by Dr Janine Gray and Dr James Brown.

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| | |
|---|---|
| AHD | Acromiohumeral distance |
| AIC | Akaike’s Information Criterion |
| AMEDA | Active movement extent discrimination apparatus |
| CI | Confidence Interval |
| CKCUEST | Closed Kinetic Chain Upper Extremity Stability Test |
| ER | External rotation |
| ERS | External rotation strength |
| GH | Glenohumeral |
| GIRD | Glenohumeral internal rotation deficit |
| GM | Gluteus Medius |
| HAR | Horizontal adduction range |
| HAS | Horizontal abduction strength |
| HHD | Hand-held dynamometer |
| HREC | Human research ethics committee |
| ICC | Intraclass correlation coefficient |
| IQR | interquartile range |
| IR | Internal rotation |
| IRS | Internal rotation strength |
| KG | Kilograms |
| KJOC | Kerlan-Jobe Orthopaedic Clinic |
| MSV | Musculoskeletal variables |
| MTS | Maximal throwing speed |
| ND | Non-dominant |
| ODI | One day international |
| PM | Pectoralis minor |
| PML | Pectoralis minor length |

| | |
|---|---|
| ROM | Range of motion |
| SD | Standard deviation |
| SUR | Scapula upward rotation |
| TA | Throwing accuracy |
| TP | Throwing performance |
| TS | Throwing speed |
| UTS | Upper trapezius strength |
| VIF | Variance inflation factor |

# CHAPTER 1- INTRODUCTION- BACKGROUND AND OVERVIEW

## 1.1 BACKGROUND

Elite performance guidelines recommend that in order to achieve optimal performance, specificity and deliberate practice for the intended task should be performed.[1] Prior to any attempt at improving performance, identification of contributing factors to performance is important. Cricket consists of three different disciplines, each requiring specific musculoskeletal variables that contribute to optimal performance of that task. Compared to batting and bowling, there is a paucity of research investigating performance requirements of fielding.[2,3] Traditionally, fielding which consists of either catching or stopping the ball and returning it as fast possible to the middle or towards the stump, has generally been regarded as a low intensity activity, with intermittent bursts of explosive movement.[2] However, while this may apply more to the longer format games like test cricket, there is a rise in the popularity of the shorter and faster paced T20 cricket.[4,5] Consequently, fielders are subjected to a higher game intensity due to an increased demand on fielding which requires more frequent throws from the outfield.[4,5]

Overhead throwing performance which consists of throwing speed and accuracy is an important component of efficient fielding in cricket as well as in other sports such as baseball, handball and water polo. It is described as a complex motion that requires the interaction of multiple-joint movements and is influenced by a number of kinetic and kinematic variables.[6–8] An optimal throw requires good co-ordination between the proximal segments of the body including the lower limbs and the more distal segments like the fingers to maximize the transference of forces between body segments to produce a fast and accurate throw.[7–9]

While overhead throwing may appear similar between baseball positional players, pitchers and cricket fielders, cricketers have been reported to have inferior throwing performance for both speed and accuracy compared to baseballers.[10] This is not surprising as throwing specific training is emphasized more in baseball.[10] However, as the need for improved throwing performance is rising in cricket fielding due to increased T20 game demands, it is important to determine the specific factors that may contribute to optimal TP in cricketers.

Ignoring the effects of external environmental conditions, the speed and accuracy of a balls' trajectory relies on the anthropometric,[11–13] musculoskeleta,l[14–16] biomechanical,[17,18] and training history[19,20] characteristics of the thrower. Identification of modifiable variables that are correlated with TS and TA may assist in improving TP in cricketers.

## 1.2 KEY RESEARCH AREAS OF FOCUS

A paucity of knowledge and research exists for overhead TP in cricketers. While there have been more studies done in baseball and handball throwing performance, direct inferences of these findings may not be fully applicable to cricket players, as the physical attributes required by cricketers of different expertise levels are not clearly identified or understood.

### 1.2.1. Musculoskeletal contributors to throwing performance

Research has found that tests such as the 'Lateral to Medial Jump' and "Medicine Ball Rotation Throw' which mimicked both the movement and speed of throwing were good predictors of TS.[14] However, these movements are complex and rely on the interaction of many other smaller segments that are part of a complex kinetic chain. These smaller segments of the kinetic chain can be broken down into isolated  strength and flexibility measures which may help to identify 'weak spots' or breaks in the kinetic chain that need to be addressed.[21] Identification of these 'weak spots' could include musculoskeletal variables that have been previously associated with performance such as shoulder rotator strength[11,14,22] and shoulder external range of motion[23,24]. In addition to this, the selection of variables could include variables that have previously been associated with shoulder injury. The rationale behind this is that shoulder performance/function cannot be separated from shoulder health/integrity. Good performance relies on a healthy functioning shoulder. The presence of shoulder dysfunction or discomfort will limit the potential of the shoulder to perform adequately. This method may prevent further reinforcement of 'compensatory patterns' or the 'catch up' phenomenon which may lead to a reduction in TP or even increase the risk of developing an injury.[21,25]

### 1.2.2. Comparison of musculoskeletal contributors to performance between groups

A recent paper has identified significant kinematic differences between amateur and elite cricketers,[26] which may have an impact on TP. No study has formally investigated the musculoskeletal differences between amateur and elite cricketers, and what these differences could mean for throwing performance.

## 1.3 THESIS OVERVEIW

The research presented in this thesis comprises five chapters designed to investigate the factors that influence TS and TA in South African amateur and elite cricketers. Two chapters in this thesis are structured as formal research manuscripts for a peer-review journal and includes an abstract, introduction, methods, results, discussion and conclusion.

A review of literature on variables influencing TP (musculoskeletal, biomechanical, workload and experience level) in cricket and other overhead sports is presented in Chapter 2. This is followed by Chapter 3 which investigates the influence of musculoskeletal variables on TS and TA in amateur cricketers (this paper has been submitted and is awaiting review). A comparison of musculoskeletal variables between amateur and elite cricketers and its varying degrees of influence on TP is presented in Chapter 4. The summary and conclusion section will complete this thesis in Chapter 5.

## 1.4 AIMS AND OBJECTIVES

In an attempt to understand the influences of the physical characteristics that contribute to throwing speed and accuracy in amateur and elite South African cricketers, the primary aims of this MSc thesis are:

1. To investigate the influences of musculoskeletal variables on throwing speed and accuracy in amateur cricketers. A novel throwing accuracy measure was introduced to assess this parameter of throwing.
2. To investigate whether the musculoskeletal variables influencing throwing performance in amateur cricketers are different to elite cricketers.
3. To compare the musculoskeletal profiles of elite and amateur cricketers

# CHAPTER 2: REVIEW OF THE LITERATURE: FACTORS INFLUENCING THROWING PERFORMANCE IN CRICKETERS

## 2.1 INTRODUCTION

The game of cricket involves batting, bowling and fielding. Each of these disciplines require different skills and physical capacities.[3] Efficient fielding, which can be defined as dismissing the batsman or reducing the run rate; is a multi-tasked activity which requires good catching and throwing skills as well as an appropriate physical conditioning needed to sprint, jump and/or dive when retrieving the ball.[2] A fielder is required to retrieve the ball and subsequently return it as quickly and accurately as possible to either the wicket keeper, bowler, other fielder, or directly towards the stumps. Fielders return the ball by performing an overhead, sub-marine or side-arm throw.[27] Overhead throwing is a powerful movement that uses both elastic and kinetic energy to generate fast throwing speeds.[7] Due to its forceful and dynamic nature, it has been shown to be associated with upper-limb injuries in many overhead sports.[8,28–30] Eighteen percent (11-25 %) of elite South African cricket players have been reported to sustain a shoulder injury in a single season which is similar to previous reports of 15-36% in elite Australian junior cricketers[31] and 23% in professional English county cricketers.[32] Remarkably, 58% of shoulder injuries in South African cricketers was caused by throwing[33] and resulted in modifying throwing technique to continue fielding. Even though players may often continue to play in the presence of shoulder pain, it has been shown to negatively affect TS and TA.[34] Further, while injured players may have continued to play by modifying throwing techniques,[33] ‘hiding’ pathology in a T20 format game would be more challenging as a result of the increased fielding demands.

Research in overhead throwing has focused on injury prevention[35,36] in baseball,[37–39] handball,[40,41] tennis,[42] cricket,[43,44] and water polo[45] as well as throwing performance in the same sports.[12,14,15,22,46] Musculoskeletal screening tests which have measured variables such as joint range of motion, strength, flexibility and muscle endurance have been used in previous studies as a tool to help identify potential risk factors that may lead to injury in baseball,[38,47–50] handball,[40,41,51,52] and water polo.[45] While injury prevention is a topic that has been significantly investigated, a systematic review by Asker et al. (2018)[36] revealed that the overall evidence on potential risk factors for shoulder injury in overhead sports is limited, and suggested that performance testing or return to play guidelines may be beneficial to measure the player's shoulder functionality. There is limited research that has investigated the impact of musculoskeletal variables on throwing performance.

Throwing performance is made up of both throwing speed and throwing accuracy. While TP has been better researched in sports such as baseball[15,16,24,53] and handball,[12,54–56] there is only a limited number of studies that have investigated contributors to TP in cricketers.[14,57] Further, a measure of throwing accuracy has only been included in a few studies investigating the association between musculoskeletal variables and TP.[10,56] Throwing accuracy comprises both physical and visuomotor adequacies,[58] therefore making identification of its contributors a more complex investigation.

Although there is some cross-over of the physical requirements required to throw effectively between sports, the nature of the game's demands differ between sports, thereby possibly affecting the players musculoskeletal profile.[27] For example, a baseball pitcher throws from a standard position and is not influenced by time limitations, while cricketers throw from a more dynamic position and are under time pressure to return the ball to the middle as quickly as possible.[27] These differences over time may influence the physical attributes required by the cricketer to achieve this end. Interestingly, while the requirements of fielding in cricket are similar to that of baseball fielding, baseballers are still capable of greater throwing performance. These differences could be a result of the differences in the traditional training structures and practices between the two sports and not merely just as a result of the game demand. Due to repeated exposure to external rotation of the shoulder when pitching, baseballers have shown adaptive osseous changes causing increased humeral retroversion of the humeral head,[59,60] which has been shown to positively influence TP.[23,24] Conversely, these performance-enhancing adaptive osseous changes are not shown to occur readily in cricketers.[43] Adding to complexity and variability of the relationship between musculoskeletal factors and TP are varying game formats and individual musculoskeletal variability between players of the same sport. A T20 cricket game format has been shown to be more physically intense compared to One Day and Test Cricket due to the number of balls played in a much shorter time period.[2,5] Since varying workloads may impact the musculoskeletal system, game formats which are of a higher intensity may illicit different changes to the musculoskeletal system.[61] Even a single cricket fielding session has been shown to result in a temporary reduction in shoulder internal range of motion which may subsequently contribute to workload-acquired shoulder throwing injuries or musculoskeletal adaptation.[62] A similar finding of temporarily reduced shoulder internal rotation range of motion after pitching was also found in baseballers.[63] An increased workload has been associated positively with increased upper-limb injuries in cricket,[64] however evidence on the effects of these workload-related musculoskeletal changes on TP in cricket is limited.

The musculoskeletal profile of throwing athletes may differ between experience levels of the same sport due to musculoskeletal adaptative changes like increased shoulder external rotation range of motion[65] or muscular strength differences,[19] both of which have been shown to influence throwing speed in handball[66], cricket[14], water polo[11] and baseball[24] (Table 2.1). Evidence on the effects of these musculoskeletal differences between amateur and elite cricketers and how these differences may affect TP is limited.

The purpose of this review is to investigate the factors that contribute to overhead TP in cricket and other sports, as well the potential influence of playing level on these factors.

## 2.2 OVERHEAD THROWING PERFORMANCE

Throwing performance is made up of TS and TA. Many overhead throwing sports like baseball, handball, water-polo and cricket, are reliant on players with good throwing capabilities. Efficient overhead throwing is a complex movement that involves multiple smaller movements performed together in a specific order.[8] The kinetic chain is a term that best encapsulates all the components of an athletes body that contribute to the performance of a throw and is described as a system that allows for the transference of forces and motions throughout the body to deliver an efficient throw.[6,8] An effective kinetic chain is a combination of three main characteristics; (1) Optimal anatomy in all segments; (2) optimal physiology (muscle strength, flexibility etc); and (3) optimal mechanics (appropriate distribution and transference of forces across motions).[8] However, it should be noted that TP is not merely a sum of these three physical parts. Cognitive control,[67] sensorimotor control,[68] anxiety level,[69] and proprioceptive acuity of the shoulder[70] have all been shown to have some effect on throwing accuracy. Interestingly, 'quiet eye' training which taught participants 'optimal gaze control' when aiming at a target was shown to be more effective in improving accuracy in basketball throws than training focussed on optimising the physical stance position and throwing biomechanics.[67] While these sensorimotor mechanisms are important pathways which form part of the preparation leading up to an efficient throw,[68] an in-depth discussions on this topic is beyond the scope of this paper which focusses on the physical contributors to throwing performance.

## 2.3 CONTRIBUTION OF THE MUSCULOSKELETAL SYSTEM TO THROWING PERFORMANCE

A musculoskeletal profile includes non-modifiable features such as skeletal structures like limb length, as well as modifiable features like muscle strength and flexibility. While there are some obvious biomechanical similarities in overhead throwing between sports, little is known about the contribution of relevant musculoskeletal variables to overhead throwing between sports.

### 2.3.1 Joint range of motion, strength and power

While musculoskeletal variables have been investigated more commonly in baseball and handball, limited evidence in cricket has found variables such as muscle strength and flexibility to be associated with TP in cricket.[14,71] Freeston et al. (2016)[14] concluded that tests which mimicked both the movement and speed of throwing were good predictors of TA. However, tests that were found to be correlated to TS such as the 'Lateral to Medial Jump' and "Medicine Ball Rotation Throw' are complex movements and rely on the contribution and synchronization of many segments of the body.[72] The linkage system between smaller movements and these complex movements such as the lateral to medial jump and medicine ball throw is referred to as the kinetic chain and is further described in the biomechanics below.[9] During a throw, these smaller segments of the body do not work in isolation, however they can be clinically measured separately. These isolated measures may help us determine the strengths and weaknesses of each part of the kinetic chain, thereby helping to identify ‘weak spots’ or breaks in the kinetic chain that need to be addressed.[21] This method may prevent further reinforcement of ‘compensatory patterns’ or the ‘catch up’ phenomenon which may lead to a reduction in TP or even increase the risk of developing an injury.[21,25]

Several studies have investigated the relationship between musculoskeletal variables and TS, while only a few have included accuracy in the total measure of throwing performance. Glenohumeral external rotational range of motion,[23,24,53,73] shoulder rotational strength,[14,51,52,74] hip strength,[14–16] rotational hip mobility,[57] shoulder proprioception,[70,75] and various anthropometric[12] variables have featured in studies investigating TS in a number of sports (Table 2.1) .

**Table 2.1** A summary of the musculoskeletal variables associated with throwing performance- speed in overhead sports

| Variable associated to throwing performance | Sport/ Population | Effect on throwing performance |
|---|---|---|
| **Anthropometrics** | | |
| Body mass[12,13]<br>Body stature[11,13]<br>Age[76] | Handball,[12,13] Baseball,[76] Water polo[11] | Body mass predicted throwing velocity.[12] Pitch velocity correlated to age and body height.[11,76] |
| **Range of Motion/Flexibility** | | |
| Glenohumeral external range of motion[23,24,53,73] | Baseball[23,24,53,73] | Varied results. An increased ER ROM was positively associated with pitching speed.[23,24] No association with throwing speed was also reported.[53,77] |
| Hip and Thoracic mobility[57] | Cricket[57] | Decreased hip ROM and thoracic region (stiffer trunk) correlated to increased throwing speed.[57] |
| **Upper limb strength/power** | | |
| Shoulder internal rotation strength[11,14,22] | Water polo,[11] Cricket,[14] Handball[66] | GH Internal rotation strength/ IR torque is positively correlated to throwing speed.[11,14] Zapartidis et al. (2007)[66] found no correlation to throwing velocity in handball. |
| Shoulder external rotation strength[51,52] | Handball[51,52] | Increased ER strength was not correlated to throwing speed.[51,52] |

| Variable associated to throwing performance | Sport/ Population | Effect on throwing performance |
|---|---|---|
| Medicine ball throw (power)[12,14] | Handball,[12] Cricket[14] | Medicine ball throw (upper body power) was positively correlated to throwing speed.[12,14] |
| **Lower limb strength/power** | | |
| Hip abduction strength[16] | Baseball[16] | Hip abduction strength was an important fitness variable for maintaining ball velocity during a baseball game.[16] |
| Lateral to medial jump[14,15] | Baseball,[15] Cricket[14] | Lateral to medial jump correlated positively to throwing speed.[14,15] |
| **Kinetic chain / shoulder proprioception** | | |
| Kinetic chain[6,78,79] | Basebal,l[9,78,80] Handball[79] | Temporal (timing) and kinematic changes such as lead knee flexion and forward trunk tilt were associated with changes in throwing velocity.[78,80] Timing and trunk movement associated with throwing speed[79] |
| Shoulder proprioception[70,75] | Water polo,[70] Baseball[75] | Hams et al.(2019)[70] reported that in-water shoulder proprioception is related to throwing performance in water polo players while an earlier study reported that it was not related to throwing performance in baseball players.[75] |

Glenohumeral internal and external range of motion is frequently measured in research investigating shoulder pathology and a shift in the arc of motion of throwers has been identified.[38,50,65,81–86] While a large body of research exists on this topic, a recent review has concluded that physiologic adaptation of bone and soft tissue in overhead throwers generally does not result in significant pathology and concluded that the causative link between normal adaptation from a history of throwing and injury remains uncertain.[65] An increased glenohumeral external range of motion has been assumed to be advantageous for cricket TP potentially due to an increased wind up created in the cocking phase.[27] Reinold et al. (2018)[24] reported that pitching velocity was higher in baseball players with increased glenohumeral external rotation. Similarly Werner et al. (2008)[23] reported that maximum glenohumeral external rotation was positively associated with ball velocity in baseball players. Conversely, Keller et al. (2015)[73] as well as Marsh et al. (2018)[53] found no association between glenohumeral external rotation and pitching speed. The mean external rotation between these studies ranged from 122°- 157°and were not vastly different in their standard deviations, signifying a fair comparison of populations. While evidence on the relationship between external rotation range and TS is conflicting, there is no evidence on the relationship between TS and shoulder rotational range of motion in cricket throwing.

Shoulder rotational strength is a common variable associated with throwing speed to varying degrees.[11,14,51,52,66] Increased shoulder rotation strength was positively correlated with TS in water polo[74] and cricket,[14] while no change in speed was observed for increased shoulder strength in two handball studies.[51,52] This suggests that there is no guaranteed positive relationship between shoulder rotational strength and speed, highlighting that TP may be associated with different musculoskeletal variables across different sports. Upper limb power as measured with a medicine ball throw correlated positively to TP in cricket, demonstrating that shoulder muscle power is also an important variable for TS.[12,14]

Although hip abduction strength has been shown to be an important contributing variable to TS especially in baseball,[9,16,87] no study has investigated it’s association to TP in cricketers.[16]

However, while not directly a measure of hip abduction strength, lateral to medial jumps which require hip abduction strength, have been correlated to increased throwing velocity in both baseball pitchers and fielders[15] and cricketers.[14]

### 2.3.2 Shoulder Proprioception

Shoulder proprioception which is the ability to sense joint movement and position has been associated with injury risk and performance in throwing populations.[88–90] However, evidence shows that this relationship may vary between overhead sports.[70,75] Active Movement Extent Discrimination Apparatus (AMEDA) is a mechanical device that has been used to assess shoulder proprioception acuity by measuring the players' perception of their shoulder joint-position in relation to a position known to the testers. The results of the AMEDA test were not associated with TP in baseball players.[75] Freeston et al. (2015)[75] suggested that proprioception throughout the kinetic chain may be a better indicator of TP in baseball compared to an isolated shoulder proprioception measure. Similarly, Hams et al. (2019)[70] reported that 'on-land' AMEDA proprioceptive testing was not associated with TP but the 'in-water' AMEDA testing was significantly associated with TP in female water polo players. While testing methodology was similar between 'on-land' and 'in-water' groups, the differences reported may be related to the effect of water as the base of support in water polo.[70] While evidence on the effects of shoulder proprioception on TP in cricket is limited, a relationship similar to baseball could be expected due to the use of the thrower's kinetic chain, which relies on the cumulative proprioceptive contribution of all the joints. Evaluating the proprioception of just the shoulder joint in cricketers may provide limited information.

### 2.3.3 Anthropometric characteristics

While anthropometric variables do not fall directly within the scope of musculoskeletal variables of interest in this review, its overall contribution cannot be ignored and should also be taken into consideration. Body mass,[12,13] body height,[11,76] and age[76] were predictors of TS in a number of studies (Table 2.1). Body mass correlated positively to TS in handball studies.[12,13] Body height/length was also positively correlated with TS in handball[11] and baseball.[76] Interestingly, Sgroi et al. (2015)[76] reported that each increase in 2.54 cm in height was associated with a 1.93 km/h increase in throwing velocity in youth and adolescent baseball pitchers. Further, it was also reported that each year of age was associated with an increase of 2.41 km/h in throwing velocity.[76]

In summary, the contribution of musculoskeletal variables to TP is a complex process that is subject to variation, and therefore cannot be conclusively generalised across different overhead throwing sports.

### 2.3.4 Musculoskeletal profile differences between cricketers and other overhead sports players

Dutton et al. (2019)[43] reported that the musculoskeletal adaptations of a cricketer's shoulder is different to baseballers and do not have a 'classic thrower's shoulder'. Cricketers did not have the compensatory shoulder external rotation gain commonly found in baseball pitchers, they had downwardly rotated scapulae, a weaker serratus anterior muscle, weaker shoulder rotational strength and a substantially shorter posterior shoulder capsule and pectoralis minor.[43] While these changes were not directly linked to performance in the study, it is possible that the reduced shoulder rotational strength of the cricketers may contribute to a reduced throwing performance as this variable has been previously linked to performance.[11,14,22] There is no conclusive evidence that reduced external range of motion has a negative effect on TP (Table 2.1), however, it is possible that the lack of external rotation gain in cricketers,[43] accompanied with glenohumeral internal rotation deficit may limit the ability to produce elastic energy to contribute to ball velocity.[27] Lower limb strength and power as measured with a 'lateral to medial jump test' and dynamometry has been shown to contribute to TS in both cricket[14] and baseball.[15] Baseballers have been reported to have significantly stronger gluteus medius muscle strength than cricketers.[43,91] Since Yanagisawa and Taniguchi (2018)[16] reported that hip abduction strength (gluteus medius strength) was an important variable to maintain TS, a reduced gluteus medius strength could be regarded as a potential cause for the lower throwing speeds found in cricketers.

In another study, Freeston and Rooney (2014)[10] reported that cricket players had inferior TP compared to baseball players even when the test was more specific to the demands of cricket (Table 2.2). While Freeston and Rooney (2014)[10] did not describe the musculoskeletal profile differences between the two groups, it is possible that a larger focus on throwing-specific training and strength training in baseball as compared to a greater batting and bowling focus in cricket[2] may have contributed to the superior TP in the baseball group.[10] Further, Freeston et al. (2015)[92] reported that cricketers had a reduced ability to maintain accuracy at high throwing speeds, which could be a sign of poor throwing-conditioning for the specific task of overhead throwing.

Moreover, cricketers as a population were particularly vulnerable to shoulder pain and injury.[32,85,93,94] While many players continued play in the presence of pain, 94% of injured players reported a reduction in TP from the outfield.[95] Shoulder pain, specifically subacromial pain was shown to negatively affect throwing accuracy and muscle strength in a lay population.[34] Interpretation is limited as this was an experimental study done in a non-throwing population. While adaptations in throwing technique were made in order to maintain TP in cricketers with shoulder pain,[33,95] TP of cricketers who continue playing in the presence of some pain has not been investigated.[34]

## 2.4 CONTRIBUTION OF THROWING BIOMECHANICS TO THROWING PERFORMANCE

In cricket, the need to return the ball as fast as possible after retrieval is a critical skill for efficient fielding and requires the fielder to assume a position necessitated by the given fielding situation rather than assuming a standardised throwing stance.[27] Since a fielder could end up in a variety of body positions after ball retrieval, it makes throwing practice for these possible situations more challenging and difficult to predict. In an actual game situation, the cricket throw differs to baseball pitching mainly due to the initiation of the throw being from a more dynamic position as compared to a static position in baseball pitching.[27] While there may be similarities between baseball and cricket fielding demands, cricketers remain less proficient throwers.[10,27]

Overhead throwing is a complex movement that has been traditionally described as having six different biomechanical segments that are all intricately linked to form an overall efficient throw.[7] The stages of the overhead throw include the wind up, stride, arm cocking, arm acceleration, arm deceleration and follow-through.[7] These segments are understood to interact and work together via the kinetic chain.[9] Even though technique differences may exist between sports, an efficient kinetic chain is vital for TP and injury mitigation in all types of throws.[8] Biomechanical concepts that influence the efficiency of an overhead throw include the sequential pattern of throwing, lead foot contact, preparation phase, arm acceleration and the instant of ball release.[27] In order for TS to be maximised, the ideal sequential pattern of throwing has been described for baseball or softball throwers as forces moving first from the pelvis, upper trunk and upper arm, forearm and then to the hand.[27,96] Further, these biomechanical phases have also been described as the degree of shoulder rotation rather than the sequence of back foot strike to ball release when analysing a throw performed from a stationery position.[26] Although these concepts are similar across overhead throwing sports, game demands may result in changes to the ultimate execution of each of these biomechanical phases.

### 2.4.1 Biomechanics in baseball throwing: Influences on throwing performance

Baseball is a widely researched overhead sport due to its popularity in the USA and Japan.[49] Baseball research regarding overhead throwing is predominantly concerned with pitching, with less focus on throwing performed by the fielders.[49] A pitch throw in baseball is a controlled movement done statically on a mound (stable base of support).[97] A baseball pitch is performed without any external distractions such as reacting to a change in direction or time constraints such as in the case of cricket fielders needing to return the ball in limited time.[27] This specific game demand seems to allow the pitcher to successfully give each of the six segments of throwing its due attention, and therefore possibly maximizing the speed potential of the throw.

In a recent review, kinematic variables such as shoulder horizontal adduction, upper torso forward flexion, maximal shoulder external rotation, upper torso rotation angle, upper torso lateral flexion, lead knee flexion and forward trunk tilt were key features associated with increased ball velocity in baseball players.[80]

Previous studies have shown elite baseballers to throw significantly faster and more accurately than elite cricketers.[10,15] While it may be argued that throwing is a primary skill practiced by baseballers, and a discipline which receives less focus in cricketers, observing the biomechanical differences that contribute to this performance difference may provide insight into the variables which may influence throwing performance.

Subsequently, due to the repetitive load placed on the shoulder joint when throwing overhead in baseball, adaptive changes of the shoulder joint like 'glenohumeral internal rotation deficit (GIRD)' partly due to reduced humeral retroversion in pitchers, tends to occur more readily in this population,[60,98] compared to cricket.[43] While cricketers have also been reported to possess GIRD, the reduction in IR is not accompanied by the compensatory gain in ER.[43] The effects of these adaptive change on performance and injury risk are debatable, with no conclusive evidence to prove if humeral retroversion helps to mitigate or increase the risk of injury.[65,98] While the mechanism affecting the shoulder rotational profile may differ between sports, the influence of shoulder external rotation gain on TP has also shown to be varied, some studies found a positive correlation between increased external rotation range and TS,[23,24] while other studies found no correlation between the measures.[53,73]

### 2.4.2 Overhead throwing biomechanics in other sports

The demand of a specific sport appears to have an effect on the biomechanics and physical requirements of the overhead throw in (a) water polo, (b) handball and (c) volleyball.

#### a. Water Polo

A fundamental biomechanical difference in water polo players is the lack of a stable base of support (the use of an egg-beater kick compared to standing on the ground in cricket) when throwing. This minimises the wind up and stride segments of the traditional biomechanical phases of throwing.[45] This change in the traditional kinetic chain pattern means that most of the force production would be a combined effort of the trunk, shoulder and wrist musculature with some contribution from the lower limbs, most especially in attempting to elevate the upper body out of the water.[45] Further, water-polo players have also shown a gain in shoulder external rotation as a result of adaptive osseous and soft tissue adaptations which may provide an advantage in throwing speeds generated.[70,99]

**b. Handball**

Based on a recent scoping review of 19 relevant articles on handball kinematics and kinetics, the handball throw is reported to be characterised by large glenohumeral external rotation and abduction with minimal shoulder flexion and extension.[100] Further, it has been reported that handball does not follow a proximal-to-distal sequencing as the elbow achieves its maximal linear velocity before the shoulder.

***c.* Volleyball**

A volleyball spike may appear to have similar kinematics to other overhead sports such as handball, however a significant difference in trunk and pelvis rotation is present due to the lack of floor contact (base of support) during the cocking phase of a volleyball spike.[79] Differences of increased shoulder internal rotation and increased shoulder flexion angle compared to handball were observed during the cocking phase of throwing.[79] This difference is believed to be the result of a delay caused by a prior increase in shoulder flexion angular velocity during the upward phase.[79]

### 2.4.3 Biomechanics in cricket throwing: Influences on throwing performance

Kinematic differences between cricket and baseball throwing include a reduced maximal glenohumeral external rotation range and a reduced thoracolumbar flexion compared to baseball throwing.[26] Cricketers were more reliant on elbow flexion and threw with a more side-arm position to accelerate the ball from maximal external rotation. Interestingly, elbow flexion was however similar between baseballers and cricketers.[26] It was expected that the more side arm throwing position would be accompanied by an increased elbow flexion to compensate for a reduced shoulder external rotation range, however this lack of compensation may help explain why cricketers threw at a lower speed than baseballers.

Throwing in cricket, when compared to baseball pitching is characterised by three main demand demands (i) a dynamic and varied throwing position compared to a more static/closed position; (ii) a time constraint to throw the ball back as quick as possible as compared to adequate preparation time; and (iii) varied throwing distances compared to a standard distance.[27]

(i) Cricket throws from the outfield need to be performed as quickly as possible in order to limit the number of runs scored by the batsman.[2] Players assume varied body positions in which the quick retrieval of the ball would be more likely, which may include diving off both feet in any direction which makes landing or throwing from a stable base of support very unlikely.[3] These unpredictable throwing-stances limit the extent to which each traditional biomechanical segment may be executed and may negatively affect the ideal 'proximal to distal' transference of force.[27,96] Throwing in this situation is unpredictable and biomechanical compromises may be made in order to fulfil the throw as quickly as possible, however further research is needed to understand the effects of this on throwing performance.

(ii) A limited time to perform a wind up for the throw decreases the potential for an adequate external rotation of the shoulder in preparation for the throw, which subsequently decreases the potential for ball speed.[27] This could be explained by cricketers adopting a more side-arm position as compared to an overhead throw to obtain the speed-accuracy trade-off necessary from a stationery position for an effective run out.[26] This demand difference which 'deprives' fielders from performing repeated maximal external rotation of the shoulder (as in baseball pitching) may result in an adaptation of the shoulder joint that is different to the typical shoulder profile of a baseball pitcher.[43] A recent study has described the shoulders of cricketers as 'atypical' to that of baseball and other overhead sports.[43] Physical differences in cricketers included a reduced gain in passive shoulder external rotation range of motion and reduced shoulder rotation strength compared to baseball.[101] Like baseball pitchers, cricketers also exhibited a reduced shoulder internal range of motion, however cricketers were not found to have the subsequent increase in shoulder external range of motion which contributes to the larger total rotation range of the shoulder in baseballers compared to cricketers.[43,102] This suggests that the reduced shoulder internal rotation range of motion found in cricketers may be caused by tight soft tissue structures as opposed to an osseous change of the humeral head.[43] Further, the time constraints during cricket fielding in a game situation may limit the extent to which cricketers can perform an adequate stride in preparation for the throw. Reduced stride length may negatively influence TP and throwing arm health due to decreased energy contribution from the trunk.[103]

(iii) Throwing distances in cricket fielding are another specific game demand that has been shown to influence the biomechanics of the throw. For example, cricket overhead throws from the outfield are not always maintained as pure overhead throws. Players tend to reduce the height of the throw to compensate for accuracy when throwing from a distance of greater than 20 metres.[27]

Although these demand differences between sports have been shown to influence throwing biomechanics, its effect on TP is unclear. Understanding the nature of cricket-specific throwing demands may help develop interventions aimed at preparing cricketers to better manage the task of maintaining good TP and minimising the risk of injury throughout the season.

## 2.5 DIFFERENCES BETWEEN AMATEUR AND ELITE SPORTSMEN

According to Araujo and Scharhag (2016),[104] a clear description of the athletes or sportsmen used as participants in a study should be provided to facilitate more accurate comparisons made between studies. The term ‘amateur’ in this review refers to an adult male athlete that is formally registered in a local club or university cricket team, actively participates in competitive cricket matches, but does not play cricket as a full-time profession.[104] The definition of an elite cricketer in this review refers to an adult male cricketer that is registered as part of the provincial or national team (state registered), participates in regular cricket training or competition as his main activity/profession, and receives monetary compensation for his participation.[104]

### 2.5.1 Differences in performance

Freeston et al. (2007)[105] reported that elite cricketers threw at a higher speeds than sub-elite cricketers. While the study reported that training experience (years training) and training volume (training frequency per week) may contribute to TP, it concluded that more research is needed to investigate the mechanism behind the difference in throwing performances between groups. Although a measure of throwing mechanics, force output, strength, power and muscle co-ordination was not measured in the study, they were proposed as mechanisms responsible for the performance differences.[105]

In another study, elite handball players threw 8% faster than amateur players,[19] while this difference was reported to be a result of higher strength values in a sub-maximal strength test, the relationship between maximal power output and throwing velocity was different between groups. The study concluded that the higher throwing velocity of an elite team depends more on upper and lower extremity power output capabilities than in amateur handball players, which signifies that the influence of variables that contribute to performance may be different between experience levels in handball.[19]

### 2.5.2 Workload & playing experience: effects on the musculoskeletal system

By definition, elite sportsmen are expected to have a higher training and playing volume (frequency per week) than amateur sportsmen, while not necessarily having greater training experience (years). Harding et al. (2018)[20] reported that years of competitive play was positively correlated to increased lead-leg hip internal rotation strength and hip abduction strength in youth baseball pitchers. Further, playing frequency and increased innings pitched in prior months, was correlated to decreased shoulder internal rotation strength. Although TP was not measured, the study suggests that the musculoskeletal changes related to playing experience and frequency may have had an influence on throwing performance.[20] Another study reported a similar finding of improved hip and lower limb strength in more experienced players.[106] Hip strength has shown to be a crucial component of an adequate thrower's kinetic chain in baseball and softball.[107]

A paper that investigated kinematic differences between elite and sub-elite male water polo players found that higher ball speed in the elite group may have been due to a greater elbow angle, quicker throwing time and reduced shoulder angle in the elite group.[106] A reduced shoulder angle or reduced pre-stretch of the shoulder was suggested to be a positive adaptation of improved kinetic chain efficiency as a result of playing experience. While this was predominantly a kinematic difference, and did not measure forces, the contribution of musculoskeletal forces would need to be an integral component in the ultimate production of TS.

While the mechanisms influencing the musculoskeletal profile and TP may not be fully understood, it is evident that musculoskeletal differences between amateur and elite sportsmen exist, and these differences may influence throwing performance.

### 2.5.3. Differences in throwing biomechanics

During an overhead throw, amateur cricketers were reported to have a longer arc of preparation before overhead throwing which could lead to a reduced TS due to delayed arm acceleration.[26] Further, amateur cricketers were reported to have increased compressive forces of the shoulder and elbow which could increase the risk of developing shoulder injury compared to elite cricketers.

Interestingly, Flesig et al. (1999)[108] tested four different levels of baseballers which included youth, high school, college and professional players and found only one out of eleven kinematic variables to be different between the four groups. Although increases of joint forces and torques were found in professional players, these differences were reported to have likely been caused by increases in muscle strength and mass as compared to differences in kinematics between the different levels.

Research has found differences in all three of these areas between elite and amateur players in a number of sports, highlighting the complex interaction of variables that contribute to optimal performance. This signifies that performance can be influenced by musculoskeletal, biomechanical and workload variations even between players of the same sport. The implications of this is that findings in one group of players cannot simply be extrapolated to another group of players of a different playing level.

## 2.6 THROWING PERFORMANCE TESTING

A fair comparison of throwing performance tests between studies require that the protocol used to measure TS and accuracy be standardised or have minimal differences in the method of testing.[109] It is also important to consider external environmental factors such as wind, glare, barometric pressure and relative humidity when designing a performance testing protocol, as these factors may affect both the velocity and accuracy measurements.[109]

Testing methodologies for TS and accuracy (Table 2.2) were designed to appropriately match each relevant sport, however this variation makes comparison of TS and accuracy between sports challenging as varying methods of assessment may have influenced the performance measurement. Traditionally, TS has been evaluated using a radar gun, however the exact positioning (behind or in front of the thrower) differ between studies. It is therefore important to consider these differences when comparing speed measurements between studies especially when comparing different sports. The four cricket studies reviewed in (Table 2.2.) used the same throwing distance for the testing speed protocol but differed in the position of the radar gun. Two studies by the same author positioned the radar gun in front of the player[10,105] while the other two cricket studies placed the radar gun behind[57,71] the player. In order to minimize the measurement error caused by varying pointing angles of the radar gun when measuring TS in cricket bowlers, Feros et al. (2018)[109] recommended that the radar gun be positioned directly behind the bowler's arm. While it is acknowledged that this study used bowling and not throwing, the effects of varying measuring angles are expected to be similar when applied to throwing tests. The TA tests differed significantly between three studies.

Freeston et al. (2014)[10] used a more technical approach by measuring a range of error parameters as described by Hancock et al. (1995).[110] While this method has shown good sensitivity and reliability to measuring accuracy, it requires the use of additional equipment which may not be accessible for teams with limited resources. Further, the processing time required to analyse the test results may become impractical if done on a regular basis for player performance monitoring. Conversely, an earlier study used a simpler scoring technique which used a single wicket as the target, where accuracy was scored based on the proximity of the ball to the wicket.[105] However, subjective tester error was reported to have slightly affected the reliability of the score. A Functional Throwing Performance Index test (FTPI) was used to measure TA in cricketers by scoring participants on how many throws landed on target within a 30 second bout of successive throwing to the target, placed 4.57m away.[71] While this FTPI test may simulate the mental stressors of an actual game due to pressures of time constraints during testing, the throwing distance used for the accuracy test did not replicate a typical throwing distance from the outfield in cricket.[71]

Based on previous study protocols, future studies investigating throwing performance in cricketers should aim to utilize an indoor testing facility with adequate lighting to minimise external environmental factors,[109] position the radar gun directly behind or in front of the thrower's arm to minimise measurement angle errors[109] and utilize an adequate throwing distance which is representative of the requirements of the specific sport. The design of the accuracy test should be both easy to administer and analyse for repeated testing sessions in varying team dynamics, while maintaining good reliability and minimal testing error.

**Table 2.2** A summary of performance testing protocols used in overhead sports

| Sport | Speed test protocol | Accuracy test protocol |
|---|---|---|
| Cricket[10,57,71,92,105] | Participants stood 20 m from the target and used regulation sized cricket balls. Speed measured with radar gun. Instructed to throw as hard as possible.[10,57,71,105]<br><br>Two studies positioned radar gun behind the player,[57,71] and the other two in-front of the player[10,105] (behind the nets). | Participants stood 20m from a single cricket stump (0.71 x 0.035m). A rubber mat and a calibration frame were placed behind the stump. Accuracy was calculated using the measure between the ball and the stump using video analysis[10]/ approximation from the stump using specifically marked zones.[105]<br><br>A functional throwing performance index test was used to measure throwing accuracy. Participants stood 4.57m from the target – a square 30.48 x 30.48 target positioned 1.22 m from the floor.[71] |
| Handball[12,13,51,54,56] | Participants Stood 7 metre/9m away from the target. Usually aimed into standard 2 x 3 m handball goal. Speed measured with radar gun.[12,13,51,54] | Raeder et al. (2015)[56] measured accuracy using video analysis (measured ball distance away from target) in addition to a 'goal success' scoring system. Participants stood 7m away and aimed into a 70 x 50 cm space in the right corner of the standard 2 x 3m handball goal |
| Baseball[15,24,53,76,92] | Participants stood on a pitching mound, 18.4 m away from target. Speed measured with a radar gun[15,24,53,76]<br><br>Participants stood 20.14m away from the target[10] | Participants stood 20.14m away from target, threw towards a 7.0 cm circular target. The centre of the target was positioned 70cm above the ground to correspond with approximate strike zone.[10] |
| Water polo[11,106,111] | Testing was conducted at an indoor aquatic facility. Participants performed 3 maximal throws from the 5-m line from the goal toward the goal. A radar gun was positioned behind the nets to measure speed.[111]<br>Poor descriptions for the two other cited studies[11,106] | Participants threw a total of 25 throws for maximal accuracy at self-selected speed towards 3 different targets of a Sniper Accuracy Trainer. Throws were recorded with a video camera and the scoring system utilised total error, absolute constant error and variable error.[111] |

## 2.7 THE RELATIONSHIP OF THROWING WORKLOAD ON PERFORMANCE AND INJURY

Throwing workload monitoring and management is an important tool to help mitigate the risk of injury in overhead sports.[112] Based on athlete training guidelines,[1,112] a well-planned workload program will provide a positive dose-response to training by adapting to an adequate stimulus/challenge. A negative response may be the result of a stimulus (workload) that is too high (overtraining) and does not allow for adequate adaptation and may result in injury.

While shoulder injury (integrity) and performance (capacity) are separate measures, they are interconnected on a continuum measure of shoulder health and performance. A healthy, asymptomatic shoulder/joint creates a stable foundation on which to build performance.[113] Although injury tracking measures in cricket use a classification system which allows coaches and managers to track injury incidence,[33,114,115] tracking the shoulder's capacity to perform often goes undetected. Interestingly Kibler and Thomas (2012)[113] reported that performance dysfunctions often precedes injury, suggesting that reductions in performance could serve as an early indicator of possible forthcoming injury. In addition, players that continued to play in the presence of pain changed throwing styles/techniques,[33] presumably in order to avoid replication of a painful motion. Although these compensations were documented, the influence of these changes on TP was not measured.

A paper investigating shoulder injury and throwing workload found that cricket players who threw more than 75 throws per week were 1.73 times more likely to get injured than players who had a lower throwing workload.[64] However, an interesting finding was that adult baseball players were able to perform 75 throws per match before it increased their risk of developing shoulder injury.[64] This finding may suggest that baseball players manage throwing workloads differently to cricketers. The lack of throwing conditioning in cricketers may explain, in part, why cricketers appear to be unable to manage the same throwing workloads as baseballers. The difference in shoulder injury risk between these two sports could either be attributed to adaptative anatomical factors or different throwing biomechanical factors discussed above.

The Kerlan-Jobe Orthopaedic Clinic (KJOC) questionnaire which is administered as a measure of shoulder function in overhead athletes,[116] was found to yield a lower score in a population of elite cricketers compared to baseballers,[43] further highlighting the probability that cricketers may be accustomed to playing with sub-optimal shoulder function and that this does not affect their role in the team which is largely determined by their primary discipline of bowling or batting.

Due to the game demand, batting and bowling skills are emphasized by cricket coaches, subsequently many hours are spent training players in the nets, while there is less focus on training for fielding and overhead throwing in cricket.[2,5] While it is suggestive that cricket players are not optimally prepared for overhead throwing as baseballers, overhead throwing has not been traditionally regarded as a primary skill required by cricketers.[10] This would be particularly pertinent in young cricketers, as age is an important factor in the adaptive changes demonstrated in baseball pitchers.[59] However, with the introduction of the T20 format of the game it has become an increasingly important physical requirement.[5]

## 2.8 CONCLUSION

In summary, throwing performance which comprises of TS and accuracy is made up of a multitude of musculoskeletal, biomechanical and visuomotor factors. While baseball players are considered a superior throwing population, it is clear that the variables which contribute to TP may be made up of different combinations of factors which are based on the nature of the relevant game demands for different sports. It is also apparent that factors such as playing experience/competitive level and workload within the same sport also influence the contributors to TP. It is therefore imperative that individual player profiles are considered carefully when attempting to improve TP in the relevant population.

# CHAPTER 3 - CAN MUSCULOSKELETAL VARIABLES PREDICT THROWING PERFORMANCE IN SOUTH AFRICAN AMATEUR MALE CRICKETERS?

**This chapter is under review as an original article:**

Ahmed, S., Gray, J., Brown J. (submitted March 2020) Can Musculoskeletal variables predict throwing performance in South African amateur male cricketers? *Journal of Sport Sciences.*

For the purposes of this thesis figures and tables as well as their captions have been placed in the appropriate places within the text of the article.

## 3.1 ABSTRACT

Optimal TS and accuracy is built on a complex interaction of multiple variables. Although strength and power has been associated with TS in cricketers, the individual muscles that contribute to optimal function of the shoulder-complex has not been adequately explored in connection with throwing performance. Consequently, this study aimed to investigate the correlation between musculoskeletal variables and overhead throwing performance in cricketers. Thirty-two amateur male cricketers were tested using a battery of 16 tests (strength, flexibility, scapula positioning) as well as a TS (TS) and a novel accuracy test (TA). Only two of the sixteen tests were correlated with throwing performance in the multiple regression analysis. Non-dominant hip abduction strength (HAS-ND) correlated positively with TS ($r = 0.38$) ($p = 0.015$): on average, a strength increase of 10 Newtons was associated with an increase in TS of 0.60 km/h (95% CI: 0.12-1.08). Non-dominant pectoralis minor length (PML ND) correlated positively with TA ($r = 0.52$) ($p = 0.004$): on average, a one-centimetre increase in the length correlated to an increase, of 0.633 points (95% CI: 0.225 - 1.041). This cross-sectional study demonstrated that from an array of musculoskeletal variables, only HAS (ND) correlated with TS, while only PML (ND) correlated with TA in amateur cricketers.

**Keywords: Throwing performance; Cricket; Fielding; Musculoskeletal; Kinetic chain**

## 3.2 INTRODUCTION

Within cricket, there are three main disciplines; namely batting, bowling and fielding. The main functions of fielding are successfully catching, stopping, retrieving and returning the ball. Returning the ball is achieved by throwing, which requires significant skill and physicality.[2]

Although many papers have investigated the science of batting and bowling, not many have investigated the requirements of effective overhead throwing, an important fielding component.[3,14] Research in other overhead sports such as baseball and handball has investigated the science of overhead throwing performance, but to date there is limited evidence in cricket.[24,27,56,117] Given that the T20 format is becoming increasingly popular, it is important to consider the impact of sub-optimal fielding, especially as T20 cricket is a fielding intensive format compared to ODI and test cricket.[2]

Throwing performance (TP) is a combination of both TS and TA.[10] The assumption is that these components are influenced by both player physiology such as muscle strength/power, and throwing technique or biomechanics.[9] Increasing muscle strength and power of the upper and lower limbs has been found to be effective in increasing TS in sports such as baseball, handball and others.[14,15,55] Freeston et al. (2016)[14] associated TS with several strength and power tests in sub-elite cricketers. In particular, the medicine ball chest pass and rotation throws explained between 66 and 70% of the variance in TP.[14] As many of these tests evaluated large parts of the kinetic chain it remains unclear which specific muscles contribute the most to throwing outputs.[14] Further, this study only evaluated TS and did not consider the contribution of TA as a parameter of TP.

Since the movement of the overhead throw is considered similar to that of other overhead sports, it has been postulated that the musculoskeletal profile of all overhead athletes is similar.[118] However, Dutton et al. (2019)[43] found that musculoskeletal characteristics of elite cricketers' shoulder joint differed significantly to baseball players, making it an atypical 'thrower's shoulder'.

Therefore, an attempt to improve cricketer's TP should begin by better understanding the relationship between the cricketer's musculoskeletal profile and TP, rather than be based on the findings of other sports. Thus, this study aims to investigate the relationship between musculoskeletal variables and TP in a group of amateur cricketers.

## 3.3 METHODS

### 3.3.1 Experimental approach to the problem

This study used a cross-sectional design to determine whether laboratory measures of muscular strength, flexibility and scapula positioning were correlated to TS and TA in uninjured amateur cricket players. Participants were seen on a single occasion during pre-season at an indoor facility in an attempt to standardise environmental conditions. Participants completed demographic data, training experience, injury history and shoulder-function questionnaires (Kerlan-Jobe Orthopaedic Clinic).[119] A musculoskeletal screening battery which comprised of sixteen variables (strength, flexibility, scapula positioning) was performed on each player. All players then completed a maximal TS and accuracy test. Bivariate analysis, as well as multivatiate linear regression analyses were conducted to determine the relationship between TS and accuracy with the 16 independent variables.

### 3.3.2 Subjects

Thirty-two male cricketers (age = 23 ± 4 years, height =176 ± 8 cm, weight = 77.5 ± 15.9 kg) that were part of the 2018/2019 cricket teams from selected cricket clubs (based in Cape Town, South Africa) and a university cricket team (University of the Western Cape) volunteered to participate in this study. The distribution of player positions consisted of 34% batters, 49% bowlers and 17% all-rounders. Any player that had a shoulder injury or was receiving treatment for an injury that impacted throwing, was excluded from the study. The study was approved by the Human Research Ethics Committee, University of Cape Town (HREC: 132/2018) (Appendix I).

### 3.3.3 Procedures

The methods used for all sixteen independent variables tested are listed in detail (Table 3.1).

**3.3.4 Summary of independent variables:** A KJOC questionnaire was administered as a measure of shoulder function.[119] Glenohumeral rotation, scapular upward rotation and glenohumeral horizontal adduction were measured using a digital inclinometer (Digi-Pas DWL80E, Digipas Technologies, Inc., Dundee, England). A caliper (Mastercraft Vernier Caliper, Mastercraft Tools, Johannesburg, South Africa) was used to measure pectoralis minor length (PML). The flexibility of the latissimus dorsi was measured using a standard goniometer. Isometric muscle strength of the upper trapezius, serratus anterior, lower trapezius, glenohumeral internal rotation, glenohumeral external rotation as well as hip abduction strength (HAS) were measured using a hand-held dynamometer (MicroFET 2, Hoggan Scientific, LCC., Salt Lake City, Utah, USA). Muscle endurance of the upper extremity (shoulder complex and trunk) was tested with a simple bodyweight test (Closed Kinetic Chain Upper Extremity Stability Test).[120]

**Table 3.1** A summary of testing sequence, protocols and reliability for all measurements conducted in this study

| Type of Measurement | Test Performed (Intra-rater reliability) | Unit of measurement | Testing position | Protocol reference | Instrument used (if applicable) |
|---|---|---|---|---|---|
| **Shoulder function questionnaire** | KJOC Questionnaire (ICC = 0.88) (r = 0,84-0.86) | Points/100 | Self-administered questionnaire | Alberta et al.[119] | Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score |
| **Pain Provocation** | Hawkin's/Kennedy (ICC = 0.93 - 0.97) | Pain/No pain | Sitting with tested arm draped over examiner's arm. Examiner stabilises the scapula and performs passive GH internal rotation with the participant's arm positioned in 90° GH abduction and 90° GH flexion | Cools et al.[121] | Yes/No for the presence of pain |
| | Jobe Test (K=1 agreement with Hawkins) | Pain/No pain | Sitting with both arms positioned at 90° GH elevation. in scapula plane and full GH internal rotation (empty can position). The examiner applies a downward force resisting further GH flexion. to both of the participant's arms simultaneously. | | |
| | Full Can | Pain/No pain | As for Jobe's test, however, both arms are now positioned in 90° GH external rotation (full can position). | | |
| **Isometric Strength** | Upper Trapezius (ICC = 0.79 – 0.96) | newton (N) | Sitting with arm by side in neutral GH rotation | Cools et al.[122] | Handheld dynamometer (HHD) |
| | Serratus Anterior (ICC = 0.79 – 0.96) | newton (N) | Supine with 90° GH flexion and full elbow extension | Donatelli et al.[101] | |
| | Lower Trapezius (ICC = 0.79 – 0.96) | newton (N) | Prone with 145° GH abduction and full external rotation (thumbs up position) | Donatelli et al.[101] | |
| | GH External Rotators (ICC = 0.78 -0.98) | newton (N) | Sitting in 90° GH abduction. 90° GH external rotation and 90° elbow flexion | Hayes at al.[123] | |
| | GH Internal Rotators (ICC = 0.64 – 0.96) | newton (N) | Same as GH ER strength | Hayes at al.[123] | |
| | Gluteus Medius (ICC = 0.90) | newton (N) | Side lie with lower leg's hip and knee flexed to 30° and upper leg passively positioned in 10° hip abduction and neutral rotation. with full knee extension. | Widler et al. and Lauder et al.[91,124] | |

| Type of Measurement | Test Performed (Intra-rater reliability) | Unit of measurement | Testing position | Protocol reference | Instrument used (if applicable) |
|---|---|---|---|---|---|
| **ROM** | Upward scapula rotation (ICC = 0.89 – 0.96) | Degrees (°) | Standing with scapula upward rotation measured at rest. 45°. 90° and 135° GH abduction. in the scapula plane. | Johnson et al.[125] | Digital Inclinometer |
| | GH external rotation (passive) (ICC = 0.89 – 0.99) | Degrees (°) | Supine. with arm positioned in 90° GH abduction. 90° elbow flexion. neutral forearm rotation and wrist in neutral. A towel roll is placed under the upper arm to ensure horizontal positioning. | Kolber and Hanney[126] | |
| | GH internal rotation (passive) | Degrees (°) | Same as GH ER ROM | | |
| **Flexibility** | Pectoralis Minor (ICC = 0.83 – 0.87) | Centimetres (cm) | Supine with arms placed next to the torso in neutral GH rotation and full elbow extension | Borstad[127] | Caliper |
| | Latissimus Dorsi (passive) | | Supine with elbows in full extension and knees at 90 flexion°. | Kendall (1993) | Goniometer |
| | Posterior Shoulder Complex (ICC = 0.91) | Degrees (°) | Supine with 90° GH flexion and 90° elbow flexion. The scapula is stabilised in retraction by the examiner. | Myers et al [128] | Inclinometer |
| **Muscle Endurance** | Shoulder complex muscle endurance test: CKCUEST (ICC=0.97) | Number of repetitions | Standard push-up position (baby plank). Prone with palms and feet on the floor. Hands positioned 91.4 cm apart. on 3.8cm wide taped lines on the floor. 3 x 15-sec attempts with 45-sec break intervals. Aim for maximum taps to the opposite hand. | Lee and Kim[120] | Masking Tape. tape measure. stopwatch |
| **Throwing Speed** | Maximum speed overhead throw | Kilometres per hour (Km/h) | Standing overhead maximal effort throw with an initial forward step in preparation for the throw. Detailed explanation in methodology | Freeston and Rooney[105] | Radar gun |
| **Throwing Accuracy** | Maximum accuracy overhead throw | Points/15 | Standing overhead maximal accuracy throw with an initial forward step in preparation for the throw (min 80% of max speed). Detailed explanation in methodology | Adapted from Freeston and Rooney[105] | Radar gun. Target Board. Cricket balls |

### 3.3.5 Throwing performance testing

Throwing Speed: Participants performed an individual warm-up which consisted of self-selected arm movements (shoulder arc rolls, dynamic stretches) followed by a standardized throwing warm-up routine: ten sub-maximal overhead throws at an increasing degree of intensity (5 x 50% effort, 3 x 70%, 2 x 90%) with a cricket ball. For the test, participants stood 20 metres away from the target (Figure 3.1). They were instructed to throw a regulation size cricket ball (approx. 7.2 cm diameter) and weight (156g) toward the target with no bounce using a forward stride from a stationary position. Participants performed two throws at maximal intensity and the highest speed was recorded as the participant's maximum TS (MTS). It was emphasized that maximum speed was the aim of the first set of two throws. This MTS value was then used as a benchmark to 'validate' the subsequent three throws which focused on accuracy. TS was measured using a radar gun (Stalker Pro, Applied Concepts, Inc. Texas, USA). The tester stood directly behind the participant and aimed the gun at the height of the participant's throwing hand. Recording commenced three seconds prior to ball release.

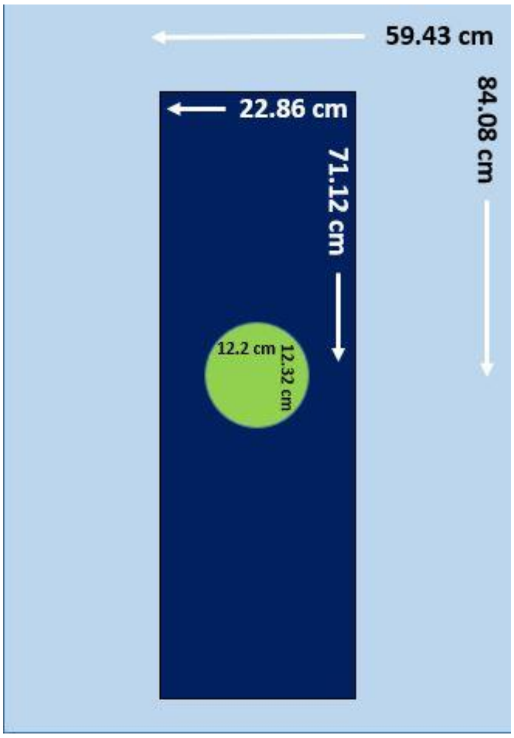


**Figure 3.1** Target board with size dimensions

Throwing Accuracy: Participants stood 20 metres away, facing the target board, which was designed using the dimensions of a standard stump set up (Figure 3.1). Participants were required to execute five overhead throws at more than 80% of the recorded MTS as accurately as possible. All players threw within their accepted range. A simple scoring technique, analogous to that used in darts, was used and points were awarded according to the site of ball contact on the target. Points were awarded as follows, (1) Three points for ball contact on the green centre circle, coinciding with the middle of the centre stump. (2) Two points for ball contact on the inner dark-blue rectangle, coinciding with the dimensions of the width and height of a standard wicket set. (3) One point for ball contact on the outer light-blue rectangle, this is technically a miss off the wicket, however a point was awarded due to proximity. Zero points were awarded if the target was completely missed.

### 3.3.6 Statistical Analysis

All statistical analyses were processed using SPSS 25.0 (IBM, Armonk, New York, USA). A t-test was performed to investigate the relationship between the pain provocation tests and TS, while a Mann-Whitney U test was used for pain and TA. Shapiro-Wilk tests were used to assess the distribution of the two dependent variables: TS and TA. To investigate the association between screening variables and these two outcomes, a two-step model building strategy was followed. Firstly, bivariate analyses were performed, using pairwise correlation matrices between all continuous independent variables and the two outcomes. A Pearson's pairwise correlation was used for TS, while a Spearman's correlation was used for TA (non-normal outcome). Independent variables that were significantly ($p < 0.05$) associated with the outcomes in these bivariate analyses (step 1) were then added to multivariate linear regressions (step 2) for each of the two outcomes. Ten cases per independent variable was used as our guide to determine how many variables could be added to the model. Regression diagnostics were assessed using a combination of the overall $R^2$ of the model, assessment of variance inflation factor (VIF) of the independent variables (to ensure no collinearity between them), Akaike's Information Criterion (AIC), and assessing the normal distribution of regression residuals. Using a combination of (i) clinical and empirical logic, and (ii) aforementioned regression diagnostics, the most parsimonious models were developed for each outcome of interest.

## 3.4 RESULTS

### 3.4.1 Average throwing speed and accuracy

Table 3.2. below illustrates the average throwing speed in kilometres per hour and throwing accuracy scores out of 15.

**Table 3.2** Throwing speed and accuracy measures (n = 32)

| Performance Measure | Mean SD | Median IQR |
|---|---|---|
| Throwing speed (km/h) | 98.9 ± 9.9 | 97.9 (IQR = 92.3 - 105.7) |
| Throwing Accuracy (Points/15) | 3.1 ± 2 | 3 (IQR = 2.0 - 4.25). |

**3.4.2 Throwing speed (TS):** Dominant ($r = 0.47$ and $p = 0.006$) and non-dominant ($r = 0.40$ and $p = 0.023$) external shoulder rotation strength (ERS - D &ND) ; dominant ($r =0.46$ and $p = 0.008$) and non-dominant ($r = 0.38$ and $p = 0.033$) shoulder internal rotation strength (IRS- D & ND) as well as non-dominant hip abduction strength (HAS-ND) ($r = 0.40$ and $p =0.025$) were all positively correlated to TS. Based on these bivariate analyses, only the three most clinically relevant variables were added to a multivariate linear regression (Table 3.3) due to sample size limitations.[129] The outcome of the regression showed that the above three variables combined accounted for 40% of the variance in the TS test ($R^2 = 0.40$). From the Pearson's correlation ERS (D) & IRS (D) were both significantly correlated to TS with an even stronger bivariate association than HAS (ND), however after adding it to the same multivariate regression these relationships with the outcome were attenuated by the presence of HAS (ND) in the same model. HAS (ND) remained the only variable significantly associated with the outcome ($r = 0.38$, 95% CI: 0.01-0.11). Thus, on average, for a 10 (N) increase in the strength of the non-dominant hip abduction, there was a 0.60 km/h (0.12-1.08) increase in TS, holding the other two independent variables constant. Refer to (appendix VII) for descriptive results for all variables tested.

**3.4.3 Throwing Accuracy (TA):** Non-dominant ($r = 0.47$ and $p = 0.007$) pectoralis minor length (PML- ND) was positively correlated to TA. Dominant ($r = -0.45$ and $p = 0.009$) upper trapezius strength (UTS-D) and dominant (r = -0.39 and p = 0.029) lower trapezius strength (LTS-D) were negatively correlated to TA. The outcome of the regression (Table 3.3) showed that the above three variables combined accounted for almost 40 % of the variance in TA ($R^2$ = 0.389). PML (ND) remained the only variable significantly associated with the throwing accuracy test (r = 0.52, 95% CI: 0.23 - 1.04). Thus, on average, for a one-centimetre increase in the length of the non-dominant pectoralis minor, there was an increase of 0.63 points (0.23 - 1.04) in TA (score out of 15), which equates to an average improvement of 4 percent (1.5% to 7% range) in the accuracy test.

**Table 3.3.** Variables significantly correlated with throwing speed and accuracy

| **Variables** | **Coefficient - standardised** | **Coefficient – unstandardized (95% Confidence interval)** | **Std. error** | **P-value** |
|---|---|---|---|---|
| ***Throwing Speed ($R^2$ = 0.400)*** | | | | |
| **ERS-D** | 0.344 | 0.109 (-0.025 - 0.243) | 0.066 | 0.108 |
| **IRS- ND** | 0.187 | 0.036 (-0.046 - 0.117) | 0.040 | 0.377 |
| **HAS-ND*** | **0.381** | **0.060 (0.012 - 0.108)** | **0.023** | **0.015*** |
| ***Throwing Accuracy ($R^2$ = 0.389)*** | | | | |
| **PML-ND*** | **0.522** | **0.633 (0.225 - 1.041)** | **0.199** | **0.004**** |
| **LTS- D** | -0.148 | -0.015 (-0.051 - 0.021) | 0.017 | 0.403 |
| **UTS-D** | -0.081 | -0.003 (-0.014 - 0.008) | 0.005 | 0.611 |

** p < 0.05, **p <0.01 ERS-D Dominant external rotation strength; IRS-ND Non-dominant internal rotation strength, HAS-ND- Non dominant hip abduction strength; PML-ND Non-dominant pectoralis minor length; LTS-D Dominant lower trapezius strength; UTS-D Dominant upper trapezius strength.*

**3.4.4 KJOC questionnaire & pain provocation tests:** The mean KJOC shoulder and elbow questionnaire score was 73.4 ± 22.7 and it was not correlated with TS. Fourteen participants displayed a positive test in at least one of the pain-provocation tests, with only two of these fourteen displaying a positive sign in two or more tests. However, TP was not different in players who did and didn't test positive for pain provocation.

## 3.5 DISCUSSION

This study builds on very limited research with regards to the contributions of musculoskeletal variables to cricket TP in amateur male cricketers. The primary outcome of this study was that non-dominant hip abduction strength (HAS-ND) was significantly correlated to throwing speed (TS) and non-dominant pectoralis minor length (PML-ND) was significantly correlated with throwing accuracy (TA), even when an array of common musculoskeletal variables were considered concomitantly.

Hip abduction strength has been shown to be an integral part of the kinetic chain, which is described as a system that allows for the effective transference of force between linked body segments, e.g. from the lower limbs to upper limbs during an overhead throw.[9]. Kibler et al.(2013)[8] postulated that weak hip abductors may cause a break in the kinetic chain which could ultimately lead to increased work-loads on the shoulder structures. Although this has clinical implications for injury risk, an inefficient kinetic chain has also been associated with sub-optimal performance in sporting activities such as throwing.[29] In baseball, HAS contributes significantly and positively to the kinetic chain and, subsequently to TS.[91,130] However, no studies have investigated this relationship in cricketers. Improved HAS may improve TS while reducing the stresses placed on the shoulder complex.[130] Further, the non-dominant hip would be the 'driving leg' which contributes to the kinetics and transfer of forces from the lower limbs to the dominant arm.[9] The gluteus medius muscle which is an important hip abductor contributes to the stability of the hip allowing for more efficient force transfer and possibly improved throwing speed

Moreover, Laudner et al. (2010)[91] measured gluteus medius (hip abduction) strength amongst 80 professional baseball players. On average, hip abduction strength recorded for pitchers was 406.0 ± 61.8 N (D) and 410.9 ± 70.6 N (ND).[91] These cricketers produced values of 278.2 ± 60.5 N (D) and 270.4 ± 62.7 N (ND). Although the HAS values were significantly lower (p<

0.001), this may not be a fair comparison due to the difference in experience level, game specificity and morphological differences between their baseball players (height = 190.0 ± 4.6 cm; weight = 90.3 ± 8.1kg) and the current cricketers (height = 176 ± 8 cm; weight = 77.5 ± 15.9 kg). However, baseball players were found to throw faster than cricketers even at sub-elite level, (109 ± 1.8km/h vs 100.4 ± 1.8km/h) respectively.[10] It would be important to further investigate what musculoskeletal and or biomechanical factors may be contributing to this difference.

Using a more ‘functional movement’ approach, Freeston et al. (2016)[14] found that tests that measured power, rather than strength alone in sub-elite cricketers were more predictive of TS. They found that the two most significant predictors of TS were the ‘Lateral to Medial Jump’ and the ‘Medicine Ball Rotation Throw’. Although not specifically tested, it would seem reasonable that based on the anatomy, movement pattern and kinetic chain requirements of these movements, that hip abduction strength contributed to the total power output of a throw. Interestingly, Freeston et al. (2007)[105] reported a similar mean TS with his cohort of sub-elite cricketers, to our cohort, 97.6 ± 8.6 km/h vs 98.9 ± 9.9 km/h respectively.

Further, pectoralis minor length appears to have a role in the aetiology of shoulder injury with an observed effect on acromiohumeral distance (AHD), scapular kinematics and shoulder range of motion.[84,131–133] The relationship of PML to TP in cricketers has never been investigated. Further, there is conflicting evidence regarding PML and its role on the shoulder joint. Viriyatharakij et al. (2016)[131] showed that stretching PM may temporarily improve a rounded shoulder posture and consequently increase AHD. Conversely, Ledesma et al. (2018)[132] demonstrated that a shortened pec minor is poorly associated with AHD. A paper by Borstad & Ludewig (2005)[133] found that a shortened PM muscle may cause altered scapular kinematics of the shoulder which appeared to be similar to scapular kinematics of individuals with impingement symptoms in a non-athlete cohort. Conversely, Rosa et al. (2017)[134] found that PML was not strongly correlated to scapular kinematics. It is important to consider that the above studies used non-athlete, heterogenous participants, making their findings less generalizable to our population of homogeneous amateur male cricketers. Further, the significance of the relationship between PML and TP has not been investigated.

The present sample of cricketers had an average PML of 15.3 cm ± 1.7 cm. On appearance, our sample of cricketers had a relatively normal PML for an athletic population,[42] however, a formal analysis between the different study samples was not done. TA was only significantly correlated to the non-dominant PML and not the dominant side. The average PML was however similar side to side (15.1 ± 2.0 D vs 15.3 ± 1.7 ND). On average, players that had a longer non-dominant PML threw more accurately.

Non-dominant PML may negatively affect TA by reducing thoracic rotation.[43] Inadequate thoracic rotation, which is needed to sufficiently wind the arm up in preparation for a throw, could potentially place the shoulder in a suboptimal position for the throw, possibly affecting TA.[43] Measuring the resting PML is different to an active measure of muscle extensibility,[135] whereby the resting length may not be the best indicator of how much a muscle can lengthen during an active movement. As such, the precise mechanism of how PML effects TA needs further investigation. However, it has been shown that stretching it may help with shoulder function even if the resting PML does not change.[134]

The scores from the KJOC questionnaire in the present cohort were lower than the average normative values for baseball[116] as well as for a cohort of professional cricketers.[43] As a group, these players appear to have a sub-optimal function of their shoulders as only 8/32 players had KJOC scores above 90, which is an average normal score for asymptomatic baseball players.[116] Although being a comparatively low score, it showed no correlation to TS and TA. Similar poor scores were also found in a cohort of professional cricket players,[43] indicating that cricketers in general, may be accustomed to playing with sub-optimal shoulder health. This further indicates possible compensatory mechanisms that cricketers may employ to continue playing as usual despite a sub-optimal shoulder function. Due to our relatively small sample size, we were limited in the number of variables that could be included in the regression analyses, and so a larger population may provide greater insights into further associations.

This study highlights the importance of considering the contribution of the entire kinetic chain in TP. Future studies should investigate whether an exercise intervention aimed at increasing HAS and PML could improve TS and TA.

## PRACTICAL APPLICATIONS

- This cross-sectional study suggests that interventions aimed at improving TS in cricketers should not be focused on the shoulder joint alone, rather it should include exercises to improve the entire kinetic chain and its constituents. Since TS correlated to HAS, and TA correlated to PML, strengthening the hip abductors (gluteus medius muscle) and stretching the pectoralis minor muscles could improve TS & TA respectively. However, the effect of these interventions on throwing performance needs to be assessed by a randomized controlled trial.
- Improving shoulder internal and external rotation strength may also contribute to throwing performance and should not be excluded from the proposed intervention.

### Disclosure Statement

The authors report no conflicts of interest.

### Funding

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# CHAPTER 4 - SIMILAR THROWING PERFORMANCE DESPITE MUSCULOSKELETAL DIFFERENCES IN AMATEUR AND ELITE SOUTH AFRICAN CRICKETERS

This chapter has been prepared in the format suited to the Journal of Science and Medicine in Sport.

## 4.1 ABSTRACT

**Objectives:** To compare the musculoskeletal profiles between amateur and elite cricketers, with the focus of identifying specific variables that may contribute to throwing performance in two different levels of cricketing experience.

**Design**: Cross-sectional investigation.

**Methods:** Twenty-six elite male cricketers from franchise and national teams, in addition to the thirty-two amateur male cricketers (Chapter 3), were recruited for participation in this study. Players underwent standardized musculoskeletal testing in addition to TS and accuracy tests.

**Results:** Six out of thirty-one musculoskeletal variables (relating to shoulder pain, strength, joint range of motion, muscle flexibility/length and scapula positioning) were found significantly different between the elite and amateur groups. When analysed individually, the two groups had different musculoskeletal variables that were linked to TP. Horizontal adduction range of motion correlated to TS ($r = 0.38$) ($p = 0.045$) in the elite group only, compared to hip abduction strength ($r = 0.38$) ($p = 0.015$) in the amateur group. Internal rotation strength correlated to TA ($r = 0.45$) ($p = 0.019$) in the elite group only, compared to pectoralis minor length ($r = 0.52$) ($p = 0.004$) in the amateur group. As a combined group, dominant shoulder internal rotation strength ($r = 0.35$) ($p < 0.05$) and non-dominant hip abduction strength ($r = 0.72$) ($p < 0.01$) correlated positively to TS, while only non-dominant pectoralis minor length was positively correlated to TA ($r = 0.50$) ($p < 0.05$).

**Conclusion:** The musculoskeletal variables correlated with performance were different between amateur and elite players. These included variables in both the upper and lower limb which emphasised the importance of strengthening the whole kinetic chain of cricketers. Further, the musculoskeletal profile of cricketers varied between experience levels. This suggests that optimal throwing performance interventions should be based on individual player assessment.

## 4.2 INTRODUCTION

Throwing is a complex motion involving multiple joint movements starting at the feet and continuing well after the ball leaves the throwers hand.[7,27] These series of movements are better known as the kinetic chain, a system which describes the transference of forces and motions through the body to produce an efficient throw or similar complex motion.[6] Efficient throwing is a product of a well-functioning kinetic chain which is influenced by a number of factors within the musculoskeletal system.[8] However, it is important to note that the relationship between the musculoskeletal variables along a kinetic chain is complex, and although similar biomechanical patterns may exist for certain movements such as throwing, it is still subject to individual variation across sports and experience levels.[27,82]

Previous studies have aimed to identify the relationship of musculoskeletal variables to TP across several overhead throwing sports. Factors such as shoulder rotational strength,[11,14,74] upper limb power,[12,14] lower-limb strength and power[14–16] and body anthropometrics[11–13,76] have been commonly investigated. While it may be a fair assumption that these overhead sports share some common musculoskeletal competencies, the combined effects of these musculoskeletal variables on TP appears to vary between sports. A study in cricket[14] and water polo[11] reported shoulder internal rotation strength/torque to be correlated to TS, while another study investigating handball players[66] found no correlation between shoulder internal rotation strength and TS. This demonstrates that while the physical requirements between sports may appear similar, the resultant effect of the musculoskeletal system on TP may vary.

Paired with the variability of these musculoskeletal variables between sports, differing experience levels within the same sport may also influence musculoskeletal function and the subsequent contribution to TP.[20,82,105] These variations could be due to anatomical adaptations like increased humeral-head retroversion found in young baseballers[59,60] and demand/load differences between experience levels[20,61,105] within the same sport.

While cricketers and baseballers both throw overhead, they may use their joints and muscles in different or modified patterns to produce a similar outcome. Overhead throwing biomechanics for cricketers exhibited a more 'preparatory arc' as compared to the 'wind-up' as noted for baseball players in preparation for a throw, and experienced greater forces at the shoulder and elbow during maximal external shoulder rotation of the throw.[26] Further, musculoskeletal differences such as a downwardly rotated scapula, reduced shoulder rotational range of movement, reduced shoulder internal and shoulder external rotation strength were some of the reported differences between baseball and cricket players.[43,101,102] Although Dutton et al. (2019)[43] aimed to investigate the correlation of these variables to shoulder injury, the effect of these musculoskeletal differences on TP may also differ.

Previous research (Chapter 3) found that from an array of relevant musculoskeletal factors in amateur cricketers, non-dominant hip abduction strength was the only variable that contributed significantly to TS, while non-dominant pectoralis minor length contributed significantly to TA. Whether the same musculoskeletal variables would contribute to TP in elite cricketers is not known.

Therefore, the aims of this study were primarily, to investigate the differences between the musculoskeletal profile of amateur and elite cricketers. Secondly, the study aimed to investigate which musculoskeletal variables were correlated with TP differences for the two groups.

## 4.3 METHODS

### 4.3.1 Participants

This study used a cross-sectional design to determine whether laboratory measures of muscular strength, flexibility and scapula positioning were correlated to TS and TA in uninjured amateur and elite cricket players. Players from amateur and professional level cricket teams were approached for participation. Players were included if they were 18 years of age or older and were part of the teams for the 2019/2020 cricket season. The study was approved by the Human Research Ethics Committee, University of Cape Town (HREC: 132/2018) (Appendix I). A total of 58 players (32 amateur and 26 elite) completed the testing on two separate occasions. Players were tested during pre-season (August 2018 & September 2019), and at the start of the official off-season while on a training camp (May 2019) to ensure they were conditioned from a throwing perspective. Data for the amateur players was collected from Chapter 3.

All players completed a questionnaire to obtain demographic data, training experience and injury history. The Kerlan-Jobe Orthopaedic Clinic (KJOC) questionnaire was administered as a measure of shoulder function in overhead athletes. Any player that had a shoulder injury or was receiving treatment for an injury that impacted throwing, was excluded from the study.

### 4.3.2 Measurement Procedures

Musculoskeletal and throwing performance testing followed the same protocol as previously completed with the amateur cricketers (Chapter 3). The test methodology is summarized in the text and (Table 3.1). In addition, refer to (Appendix VI) for full methodology of all the tests. Participants were seen on a single occasion at an indoor facility. The independent variables tested included a KJOC shoulder function questionnaire; shoulder pain provocation tests (Hawkins/Kennedy, Jobe's, Full Can); Isometric strength measures of the upper trapezius, serratus anterior, lower trapezius, glenohumeral internal and external rotators and hip abductors were tested using a hand-held dynamometer (Micro FET 2, Hoggan Scientific, LCC., Salt Lake City, Utah, USA).

Upward scapular rotation, glenohumeral internal and external rotation and horizontal shoulder adduction was measured using a digital inclinometer (Digi-Pas DWL80E, Digipas Technologies, Inc., Dundee, England). Pectoralis minor length was measured using a caliper (Mastercraft Vernier Caliper, Mastercraft Tools, Johannesburg, South Africa). The flexibility of the latissimus dorsi was measured using a standard goniometer. Upper-limb muscle endurance was tested using the Closed Kinetic Chain Upper Extremity Stability Test.[120]

The dependent variable was throwing performance, which was made up of (i) throwing speed (TS) and (ii) throwing accuracy (TA) (detailed methodology described in Chapter 3).

### 4.3.3 Statistical Analysis

All statistical analyses were processed using SPSS V.25.0 (IBM, Armonk, New York, USA). The data used for the amateur group was collected in Chapter 3. All data from both groups were combined and checked for normality using a Shapiro-Wilk test. Subsequently, to determine differences between groups, a T-Test (for normally distributed variables) and a Mann-Whitney test (for non-normal variables) was performed to compare player demographics, musculoskeletal variables and TP variables between elite and amateur groups. The p-value for rejecting the null hypothesis (no difference between groups) was set at $p < 0.002$, based on a Bonferroni-correction of the conventional p-value of 0.05 divided by the 31 outcomes being compared between the two groups (0.05/31 = 0.002).[136]

To investigate the association between screening variables and the two outcomes (TS and TA), a two-step model building strategy was followed. Firstly, bivariate analyses were performed, using pairwise correlation matrices between all continuous independent variables and the two outcomes. A Pearson's pairwise correlation was used for TS, while a Spearman's correlation (not normally distributed) was used for TA. Independent variables that were significantly ($p < 0.05$) associated with the outcomes in these bivariate analyses (step 1) were then added to multivariate linear regressions (step 2) for each of the two outcomes. Ten cases per independent variable was used as our guide to determine how many variables could be added to the model.[129] Regression diagnostics were assessed using a combination of the overall $R^2$ and statistical significance ($p < 0.05$) of the model, assessment of variance inflation factor (VIF) of the independent variables (to ensure no collinearity between them), Akaike's Information Criterion (AIC) for comparing between models, and assessment of the normal distribution of regression residuals. Using a combination of (i) clinical and empirical logic, and (ii) aforementioned regression diagnostics, the most parsimonious models were developed for each outcome of interest (TS and TA). The correlation analyses and multivariate regression analyses were done for the amateur and elite groups separately. As both groups had a similar TS and TA, a combined group statistic was also performed.

## 4.4 RESULTS

### 4.4.1 Participants

While the elite and amateur groups were similar in age, the elite group was taller, heavier and had a higher functional ability of the shoulder (KJOC score) than the amateur players. (Table 4.1). All data are expressed as mean ± standard deviation. The player position distribution in the amateur group consisted of 34% batters, 49% bowlers and 17% all-rounders while the elite group consisted of 17% batters, 79% bowlers and 4% all-rounders.

**Table 4.1** Player demographics – amateur vs elite

| Variable | Amateur (A) | Elite (E) | Comparison |
|---|---|---|---|
| Age (years) | 23 ± 4.0 | 23.9 ± 5.1 | ND |
| Weight (kg's) | 77.5 ± 15.9 | 85.7 ± 10.6 | E > A** |
| Height (cm) | 176 ± 8.0 | 183.6 ± 8.3 | E > A** |
| KJOC (score/100) | 73.4 ± 22.7 | 85.1 ± 16.0 | E > A* |

*Abbreviations: A: amateur; E: elite. *p < 0.05; **p < 0.01; ND = no significant difference*

### 4.4.2 Performance comparison between groups

There was no difference in throwing speed or accuracy between the elite and amateur players (Table 4.2) All data are expressed as mean ± standard deviation.

**Table 4.2** Throwing performance between amateur and elite

| Variable | Amateur | Elite | Comparison |
|---|---|---|---|
| Speed (km/h) | 98.9 ± 9.9 | 101.8 ± 8.7 | ND |
| Accuracy (points/15) | 3.1 ± 2.0 | 3.7 ± 2.2 | ND |

*Abbreviation: ND: no significant difference*

### 4.4.3 Musculoskeletal variables comparison between groups

Six out of 31 variables were significantly different between groups (Table 4.3). The elite group had a significantly higher dominant upward scapula rotation (at 45 degrees glenohumeral abduction), and stronger dominant and non-dominant hip abduction strength measure compared to the amateur group. The amateur group were significantly stronger in dominant glenohumeral external rotation strength and bi-lateral glenohumeral internal rotation strength (D and ND). (Interesting to note is that 15 out of 31 variables were different between groups prior to the Bonferroni correction).

**Table 4.3** Musculoskeletal variables comparison between groups.

| Variables | Side | Amateur | Elite | Superior Score |
|---|---|---|---|---|
| Upward Scapula Rotation at Rest (°) | D | 3.5 ± 2.1 | 2.9 ± 3.6 | ND |
| | NonD | 3.1 ± 2.5 | 3.7 ± 3.1 | ND |
| Upward Scapula Rotation at 45° GH Abduction (°) | D | 4.5 ± 3.5 | 7.5 ± 4.2 | Elite* |
| | NonD | 5.6 ± 3.2 | 8.6 ± 5.0 | ND |
| Upward Scapula Rotation at 90° GH Abduction (°) | D | 14.7 ± 7.3 | 20.2 ± 5.8 | ND |
| | NonD | 17.7 ± 6.5 | 22.0 ± 8.6 | ND |
| Upward Scapula Rotation at 135° GH Abduction (°) | D | 30.6 ± 7.2 | 30.4 ± 6.6 | ND |
| | NonD | 34.6 ± 7.7 | 35.7 ± 8.9 | ND |
| GH Internal Rotation-Range (°) | D | 45.3 ± 10.0 | 52.4 ± 9.6 | ND |
| | NonD | 48.5 ± 12.1 | 54.1 ± 8.4 | ND |
| GH External Rotation-Range (°) | D | 91.5 ± 10.6 | 87.8 ± 11.2 | ND |
| | NonD | 89.4 ± 10.7 | 82.1 ± 12.4 | ND |
| GH Horizontal Adduction-Range (°) | D | 15.8 ± 8.4 | 12.9 ± 7.4 | ND |
| | NonD | 13.5 ± 8.5 | 14.1 ± 8.6 | ND |
| Latissmus Dorsi-Range (°) | D | 162.4 ± 7.2 | 166.0 ± 7.4 | ND |
| | NonD | 165.5 ± 7.2 | 167.2 ± 7.2 | ND |
| Pec Minor-Length (cm) | D | 15.1 ± 2.0 | 15.1 ± 1.6 | ND |

| | | | | |
|---|---|---|---|---|
| | NonD | 15.3 ± 1.7 | 15.2 ± 1.3 | ND |
| GH External Rotation-Strength (N) | D | 131.9 ± 31.3 | 103.3 ± 26.3 | Amateur* |
| | NonD | 128.5 ± 35.6 | 105.4 ± 20.8 | ND |
| GH Internal Rotation-Strength (N) | D | 196.6 ± 52 | 145.1 ± 30.4 | Amateur* |
| | NonD | 182.1 ± 46.2 | 143.8 ± 28.7 | Amateur* |
| Serratus Anterior-Strength (N) | D | 235 ± 92.3 | 251.0 ± 51.8 | ND |
| | NonD | 243 ± 71.7 | 245.6 ± 46.1 | ND |
| Upper Trap-Strength (N) | D | 234.5 ± 61.3 | 261.7 ± 54.2 | ND |
| | NonD | 242.5 ± 56.0 | 255.3 ± 49.2 | ND |
| Lower Trap-Strength (N) | D | 74.3 ± 20.3 | 80.3 ± 25.3 | ND |
| | NonD | 63.5 ± 15.5 | 76.1 ± 24.6 | ND |
| Hip Abduction-Strength (N) | D | 278.2 ± 60.5 | 354.2 ± 47.3 | Elite* |
| | NonD | 270.4 ± 62.7 | 338.6 ± 35.3 | Elite* |
| CKUEST (taps) | *N/A* | 26.4 ± 3.4 | 29.2 ± 7.9 | ND |

*Abbreviations: D=: dominant, NonD: non-dominant; ND: no significant difference; * p < 0.002 (Bonferroni corrected p value)*

#### 4.4.4 Between group differences- distribution of measurements

Of the six variables found significantly different following a Bonferroni correction (Table 4.4), IRS (D) and HAS (ND) were concurrently found to be significantly correlated to TS in the combined group statistic. A comparison of the means and standard deviation of IRS (D) and HAS (ND) is illustrated below in (Figure 4.1). On average, the amateur group had higher shoulder internal rotation strength and lower hip abduction strength than the elite. Secondly, the plots illustrate that the elite group were a more homogeneous group for IRS (D) and HAS (ND) compared to the amateur group based on the narrower spread of measurements.

Further, while HAR (D) and PML (ND) were correlated with TS in elite and TA in combined respectively, they were not significantly different between groups. A comparison of HAR (D) and PML (ND) are illustrated below (Figure 4.1). The players appeared to have similar values for these two flexibility measurements as well as a similar distribution between groups.

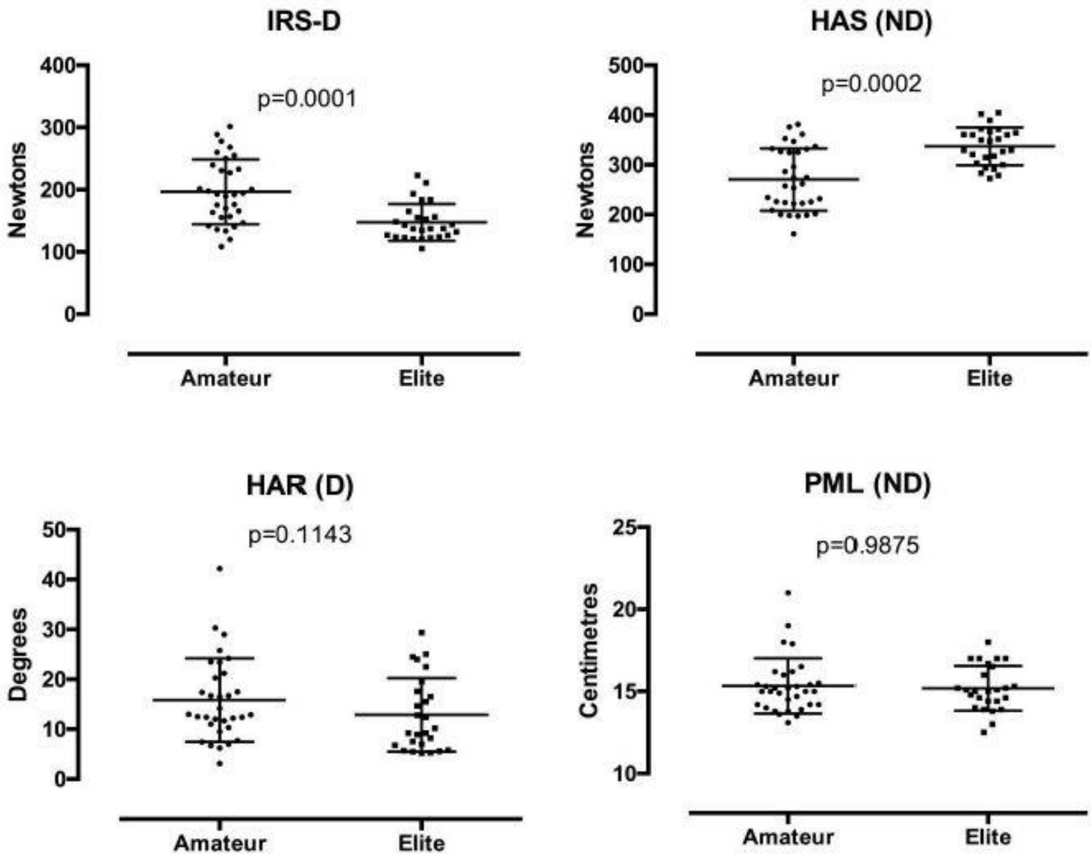


**Figure 4.1**. Comparison of IRS (D) Dominant glenohumeral Internal rotation strength; HAS (ND) Non-dominant hip abduction strength; HAR (D) Dominant glenohumeral horizontal-adduction range and PML (ND) Non-dominant pectoralis minor length between groups. All data representative of the mean and standard deviation.

### 4.4.5 Musculoskeletal variables correlated to throwing performance in combined groups- amateur and elite (n= 58)

In the bivariate analyses, throwing speed (TS) was positively correlated with dominant ($r = 0.30$ and $p = 0.02$) shoulder internal rotation strength (IRS-D); dominant ($r = 0.26$ and $p = 0.05$) upper trapezius strength (UTS-D); dominant ($r = 0.33$ and $p = 0.01$) lower trapezius strength (LTS-D); dominant ($r = 0.28$ and $p = 0.03$) and non-dominant ($r = 0.40$ and $p < 0.01$) hip abduction strength (HAS-D & ND). All five variables were added to a multivariate linear regression analysis, and together accounted for around 35% of the variance in the throwing speed test ($R^2$ = 0.35). However, of these five independent variables, only two: IRS-D (r = 0.35, 95% CI: 0.02- 0.11) and HAS-ND (r = 0.72, 95% CI: 0.04- 0.18) were significantly associated with TS in the multiple regression. The KJOC score was not associated with TS and did not alter the regressions.

In the bivariate analyses for TA, dominant (r = 0.28 and p = 0.03) and non-dominant (r = 0.32 and p = 0.01) pectoralis minor length (PML-D & ND) were positively correlated, while dominant (r = - 0.31 and p = 0.02) shoulder external rotation strength (ERS-D) was negatively correlated with TA. All three variables were added to a multivariate linear regression and together they accounted for 21% in the variance of the throwing accuracy test ($R^2$ = 0.21). However, of these three independent variables, only PML-ND (r = 0.50, 95% CI:0.03 - 1.41) remained significantly associated with TA in the multiple regression.

### 4.4.6 Musculoskeletal variables that correlated to throwing performance in the amateur group alone

HAS (ND) remained the only variable significantly associated with the TS following the regression (r = 0.38, 95% CI: 0.01-0.11). Refer to (Chapter 3) for more detail.

PML (ND) remained the only significant contributor to TA (r = 0.52, 95% CI: 0.23 - 1.04). Refer to (Chapter 3) for more detail.

### 4.4.7 Musculoskeletal variables that correlated to throwing performance in the elite group alone

In the bivariate analysis, throwing speed (TS) was positively correlated with dominant (r =0.482 and p = 0.01) horizontal adduction range of motion (HA ROM-D); dominant (r = 0.42 and p= 0.03) internal rotation strength (IRS-D); dominant (r = 0.480 and p = 0.02) lower trapezius strength (LTS-D); and non-dominant (r = 0.42 and p = 0.03) hip abduction strength (HAS-ND) . All four variables were added to a multivariate linear regression analysis, and together accounted for around 46% of the variance of the TS test ($R^2$ = 0.46). However, of these four independent variables, only HA-ROM-D (r = 0.38, 95% CI: 0.01- 0.92) remained significantly associated with TS ($p = 0.045$). in the multiple regression Thus, on average, for a one degree (°) increase in the range of dominant horizontal adduction, there was a 0.46 km/h (0.12 - 0.92) increase in TS, holding the other three independent variables constant.

In the bivariate analysis for throwing accuracy (TA), dominant (0.46 and $p = 0.02$) internal rotation strength (IRS-D) positively correlated to TA in the elite group. The outcome of the regression showed that IRS (D) accounted for 21% of the variance of the throwing speed test ($R^2 = 0.21$). IRS-D remained significantly correlated to TA ($p = 0.02$) in the elite group following the regression ($r = 0.45$, 95% CI: 0.006- 0.062). Thus, on average, for a 10 N increase in the strength of dominant internal rotation strength, there was an increase of 0.34 points (0.06-0.62) in TA (score out of 15).

### 4.4.8 Summary of variables correlated with throwing performance outcomes between groups

Musculoskeletal variables that correlated to TS and TA differed between groups (Table 4.4). Non-dominant hip abduction strength correlated to TS in the amateur group only, while dominant glenohumeral horizontal adduction range correlated to TS in the elite group only (Table 4.4). Non-dominant pectoralis minor length correlated to TA in the amateur group, while dominant glenohumeral internal rotation strength correlated to TA in the elite group (Table 4.4). However, when a combined group statistic was performed, dominant glenohumeral internal rotation strength and non-dominant hip abduction strength were correlated positively to TS and non-dominant pectoralis minor correlated positively to TA (Table 4.4).

**Table 4.4.** Variables correlated with throwing performance outcomes between groups

| Variable | Amateur | Elite | Combined Groups |
|---|---|---|---|
| | $R^2 = 0.40$ | $R^2 = 0.46$ | $R^2 = 0.35$ |
| **Throwing Speed** | Hip Abduction Strength (ND)* | Horizontal Adduction Range (D)* | Internal Rotation Strength (D)**<br>Hip Abduction-Strength (ND)** |
| ***Other variables included in the model*** | *External Rotation Str. (D &ND); Internal Rotation Str. (D &ND)* | *Internal Rotation Str. (D); Lower Trapezius Str.(D); Hip Abduction Str. (ND)* | *Internal Rotation Str. (ND); Lower Trapezius Str. (D); Upper Trapezius str. (D); Hip abduction str. (D)* |
| | $R^2 = 0.39$ | $R^2 = 0.21$ | $R^2 = 0.21$ |
| **Throwing Accuracy** | Pec Minor-Length (ND)* | Internal Rotation Strength (D)* | Pec Minor Length (ND) |
| ***Other variables included in the model*** | *Upper trapezius Str. (D) Lower Trapezius Str. (D)* | *No other variables besides IRS (D)* | *Pec Minor Length (D); External Rotation Str. (D)* |

*$*p < 0.05$, $**p < 0.01$*

## 4.5 DISCUSSION

### 4.5.1 Throwing performance of amateur vs elite cricketer

Although there was no significant difference in TS between amateur and elite cricketers, six out of thirty-one musculoskeletal variables were significantly different between groups. At the onset, this highlights that even though these cricketers did not differ in their throwing performance, the mechanism by which they produced their respective speed and accuracies may potentially be quite different. Although the distribution of players was slightly different between groups with the elite group having approximately 30 % more bowlers, it is unlikely that this would explain the lack of performance differences, as bowlers and batters are both expected to field.

Previous studies have found elite cricketers throw at greater speeds than amateur players,[105] while there is very little data on TA within cricket. Interestingly, the mean TS of the amateur group (98.9 ± 9.9 km/h) is similar to a previous group of sub-elite (97.6 ± 8.6 km/h) male cricketers (registered with 'A' grade cricket club and were of a similar age) tested in a previous study.[105] However, the mean TS for the elite group (101.8 ± 8.7 km/h) tested in the current study was lower than an elite group (109.4 ± 8.3 km/h) (registered with State First Class Cricket/ State Junior Development squads) evaluated by Freeston et al. (2007).[105] This suggests that the current sample of elite cricketers may be throwing at a lower speed than what is deemed appropriate for their level. A previous study found that 58% of injured (non-time loss) elite South African cricketers that continued play during the 2016/2017 season, reported changing throwing technique due to shoulder pain.[33] Although the present sample of elite cricketers did not report being injured at the time of testing, a number of elite cricketers had a KJOC score (a subjective measure of shoulder function) below 90 (85.1 ± 16.0 points). Kraeutler et al. (2013)[137] reported that normal values for the KJOC score in baseball players should be above 90 and that anything below could be a cause for clinical concern. Therefore, it is possible that some of the players started the season with sub-optimal shoulder function. Interestingly, the KJOC score showed no association with TP, highlighting that players may have adapted to playing with sub-optimal shoulder function. Further, although the KJOC score for the elite cricketers was higher than recorded for the amateur group (73.4 ± 22.7 points), it is possible that based on the poor shoulder strength values recorded for elite cricketers, the group may have underreported the functional ability of their shoulder in the questionnaire due to selection concerns.

Throwing accurately is a complex skill that involves both physical and mental adeptness[2]. Adequate musculoskeletal function is required to execute the throw, while the planning or timing of this movement is also dependant on visuomotor control,[58] cognitive control,[67] anxiety levels,[69] and proprioceptive acuity of the shoulder.[70] The timing of ball release from the fingers has been reported to be associated with TA.[58] There is little known on what visuomotor or musculoskeletal factors affect TA in cricketers. Freeston et al. (2007)[105] reported a speed-accuracy trade-off, whereby players throw most accurately at 75-85% of their maximum speed.

Unexpectedly, TA did not differ between groups. This may be a result of the low sensitivity of the scoring criteria. While other studies measured TA on a continuous scale,[56,105] the current study used a novel accuracy test that is different to tests used in previous research. The scoring system used was a categorical system which did not score partial points, therefore making it less sensitive to ‘near miss throws’. Players were required to throw directly at the target without any bounce over a distance of 20 metres. It may be argued that this requirement may have been too challenging and not an ideal representation of actual game play. However, contrary to this point, players were not subjected to a limited launch window[105] (reduced throwing preparation time) and/or game stress which may affect a players’ ability to throw accurately in an actual game. This indicates that both amateur and elite players may have both been generally poor at throwing accurately as is suggested by the low accuracy scores in both groups.

### 4.5.2 Musculoskeletal variables significantly different between amateur and elite

There is little evidence about the contribution of musculoskeletal factors to TP in cricketers and how differences in these variables may impact TP.[27] Variables including SUR-45 (D); ERS (D); IRS (D); IRS (ND); HAS (D) and HAS (ND) were significantly different between groups. Of the six variables, dominant glenohumeral internal rotation strength (IRS D) and non-dominant hip abduction strength (HAS ND) were the only two variables significantly correlated with TS in the combined group statistic.

### 4.5.3 Variables that contributed to throwing speed in combined groups

Glenohumeral internal rotation strength has frequently been linked to overhead throwing and is commonly featured as a variable that is positively associated with TP.[11,14,66,74] The current study confirms the findings of Freeston et al. (2016)[14] that reported IRS was significantly correlated to TS in sub-elite male cricketers. Olivier and Daussin (2018)[22] found that increased concentric peak torque of the internal rotators was predictive of throwing velocity in female water-polo players. The IRS value of the throwing/pitching arm is greater than the non-pitching arm in baseballers, signifying the possible role of IRS as a contributor to TP.[101,138] Similarly Debanne and Laffaye (2011)[12] found that increased upper body strength, measured using a bench press test, was correlated to TS in handball players.

The dominant IRS in the elite group was significantly lower than the amateur group. The IRS (D) value of the current elite group was similar to a different cohort of elite South African cricketers (145.1 ± 30.4N vs 133.5 (70.5- 312.6N)).[43] While it was unexpected that elite players would have a lower IRS than amateur players, this anomaly may be a result of throwing workload, training differences and throwing technique adaptations between experience levels. Harding et al. (2018)[20] reported that youth baseballers that played for a greater number of months in the year and had a higher pitching volume were reported to have a reduced IRS, while the number of years played was also correlated to a greater hip abduction strength in these players.[20] As this study had a cross-sectional design and did not measure changes over time, it is not possible to extrapolate these findings in baseball to the current study. However, taking into consideration that elite players train and play more frequently than amateur players, these findings are relatable to the groups tested in this study. Although the mechanism of these musculoskeletal adaptations are not fully understood, it is foreseeable that higher cumulative/seasonal throwing volumes could explain the lower internal rotation strength found in the elite group.[20]

The elite IRS (D) value (145.1 ± 30.4N) appears lower than IRS (D) values recorded for professional baseball players (178.5 ± 38.8N),[101] while IRS (D) for amateur cricketers (196.6 ± 52N) was greater than professional baseballers. Since IRS (D) and HAS (ND) remained the only significant contributors to TS in a combined-group regression, it is suggestive that the relatively low IRS may have been responsible for a reduced TS in the elite group. It may further be possible that there is greater focus on coaching and conditioning for throwing in baseball than in cricket. However, with the increasing importance of fielding in the T20 format of the game,[2] these findings may provide possible areas to be targeted in strengthening programmes to specific experience levels.

Hip abduction strength is an important variable for an efficient kinetic chain of a thrower.[6] A well-functioning kinetic chain requires a large portion of the force required for an efficient throw to be generated by the lower limbs which subsequently decreases the load placed on the upper-limbs/ shoulder complex.[8] HAS was further reported to be an important component in both the wind up and cocking phases of throwing,[91] and has been described as a significant contributor to the movement of overhead throwing in baseballers.[87] Weak hip abductors provide an unstable base for throwing, and subsequently forces the more distal segments like the shoulder and elbow to compensate in order to maintain TS or TA.[7] Yanagisawa and Tanaguchi (2018)[16] found that hip abduction strength of the pivot and stride legs (dominant and non-dominant) is an important fitness variable needed to maintain good ball velocity in baseballers, due its role in hip stabilization, as well as its contribution to efficient energy transfer from the lower limb to the trunk. Little is known about the contribution of HAS specifically to cricket TP, however, Cook and Strike (2000)[27] have reported a definite crossover between baseball and cricket throwing biomechanics. Further, Freeston et al (2016)[14] reported that a lower-limb strength test, such as a lateral jump was predictive of throwing velocity in sub-elite male cricketers. Although this test was not a direct measure of hip abduction strength it supports the role of lower limb strength in TP.

This study found the elite group (354.2 ± 47.3N) had a significantly higher HAS than the amateur group (278.2 ± 60.5N). The lower standard deviation of the elite group may be indicative that the elite group may be a more homogeneous group of players than the amateurs. A pattern of lowered standard deviation was observed for most of the strength variables for the elite group. This finding is not surprising, as training and conditioning is generally expected to be more standardised and consistent within the elite structure as compared to amateur teams. Further, it may be possible that an increased HAS in the elite group off-sets the IRS required to achieve throwing velocity, which may signify a more efficient kinetic chain due to a reduced load on the shoulder [8,29]

Moreover, Harding et al. (2018)[20] reported that playing years in baseballers was associated with increased HAS, and thereafter postulated that improving HAS in a younger, less-experienced population, would be more beneficial than for players with more years of playing experience. The results of this study support the findings of Harding et al[20] which suggest that players with more playing years (competitive) have greater hip strength. Although biological ages were similar between these groups, biological age and playing years are different measures. However, elite players train and play more cricket within a single year than amateurs, symbolising that actual 'playing years' may be different across levels.

Other variables that may be associated with TS in combined groups included upper trapezius strength (D) and lower trapezius strength (D) were found to be positively correlated to TS in the combined group correlation matrix prior to the regression analysis and were both significantly higher in the elite group. Although these variables did not remain significant following the multivariate linear regression, it appears that they may have some role in the contribution of TS.

The trapezius muscle is made up of upper, middle and lower fibres, and together are responsible for specific movements of the scapula.[139] The upper and lower trapezius fibres are both responsible for the upward rotation of the scapula.[139] The elite group in this study displayed greater scapula upward rotation at both 45°and 90°. This is further supported by the higher force measured for upper and lower trapezius muscles in the elite group. A study by Myers et al. (2005)[140] showed that throwing athletes have scapular positioning and orientation differences which include increased upward rotation, internal rotation and retraction compared to non-throwers. Although this increase in scapular upward rotation was not directly correlated to greater TP in this study, this musculoskeletal adaptation may provide a reduced risk of shoulder injury.[140]

#### 4.5.4 Variables that contributed to throwing accuracy in combined groups

Although PML (D & ND) correlated positively to TA and ERS (D) correlated negatively to TA, only PML (ND) remained a significant contributor to TA in the combined group multivariate linear regression analysis. Pectoralis minor length has been linked with variables such as acromiohumeral distance[131,132] and scapular kinematics[133,134] which are variables frequently associated with the aetiology of shoulder injuries.[40,43,118] Further, it is plausible that a shortened PML may cause altered shoulder mechanics, similar to that experienced by players with subacromial pain.[127] Wassinger et al[34] showed that experimentally-induced subacromial pain negatively affected TA. Although the mechanism of how a longer PML contributed to improved TA is not fully understood, Dutton et al. (2019) postulated that an increased PML may contribute to an improved thoracic rotation which may affect the throwers kinetic chain.[43] Rosa et al. (2017)[134] reported that stretching the pectoralis minor regardless of whether the resting length of the muscle changed, was shown to positively influence shoulder function.

#### 4.5.5 Musculoskeletal variables associated with throwing performance in elite players.

Individual group analysis revealed that musculoskeletal variables that were found correlated to TP in the elite group alone differed to variables found in the amateur and combined group correlations. Dominant horizontal adduction ROM (HAR-D) was found to be correlated to TS only in the elite group. Similarly, dominant IRS was found to be correlated to TA in the elite group alone. Although HAR (D) was not significantly different between groups, it appeared higher in the amateur (15.8 ± 8.4°) than for the elite group (12.9 ± 7.4°). However, the distribution of measurements for HAR (D) between groups appeared similar, signifying that shoulder posterior capsule length/flexibility between groups were not vastly different.

A reduced HA-ROM may signify a tighter posterior shoulder capsule.[128] Further, a tight posterior capsule has been associated with increased throwing workload and is reportedly caused by cumulative resistance to deceleration forces of overhead throwing.[141] Increased posterior shoulder tightness has been documented to be correlated to shoulder pathology,[142] and has also been associated with TS in baseball players.[80] Players who had a higher HAR

(D) in the elite group threw faster, while there was no association with TS in the amateur group. This signifies that while HAR (D) had an effect on TS in the elite group, the interaction of the posterior capsule on the shoulder joint may be different between individuals. Further investigation is needed to better understand the mechanism of how horizontal adduction range/posterior capsule tightness influences TS in cricketers.

While only 40% (amateur) and 46% (elite) of the throwing speed could be attributed to musculoskeletal variables that were measured in this study, it is important to note that these variables were different for the two groups despite a similar TS. This suggests that several combinations of a number of variables can be responsible for producing the final TS. This has significant implications when considering intervention programmes to improve TS and would seem to suggest that generic programmes may not be as beneficial as individual programmes.

### 4.6 Limitations

It is understood that this is a cross-sectional study of two groups of cricketers, and therefore these findings cannot be generalised across all cricketers of different playing levels and ages. However, this concept highlights that musculoskeletal variables may vary and fluctuate during a cricketers' career and therefore speaks to the importance of training specificity across varying cricketing levels. Further, while sample size was controlled for in the statistical analysis, future studies should aim to evaluate a larger sample size.

## 4.7 CONCLUSION

The musculoskeletal profile of cricketers varies between experience levels. Further, different musculoskeletal variables contributed to throwing performance at different levels. In the aim of improving TS and TA, these reported differences may help guide exercise intervention programs to be more specific to the relevant cricket level/individual by focusing on the identified musculoskeletal traits of the team. Future studies should investigate whether improving variables such as glenohumeral internal rotation strength, hip abduction strength and shoulder horizontal adduction range can improve throwing speed and whether increasing PML improves throwing accuracy.

**Clinical Implications**

- While there was no difference in throwing performance between experience levels, the variables that correlated to performance were different between groups.
- Individualised strength and flexibility training that focusses on addressing possible compensations of the musculoskeletal system may help ensure players' throwing capabilities are optimized at all relevant cricketing levels.

**Conflicts of interest**

No conflict of interest

**Acknowledgements**

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# CHAPTER 5- SUMMARY AND PRACTICAL IMPLICATIONS

## 5.1 SUMMARY

The aim of this thesis was to determine and understand the influence of musculoskeletal variables on throwing performance in cricketers. Further it was to compare the musculoskeletal profile between amateur and elite cricketers and to investigate if the factors that contribute to TP were different between the two groups.

While TP is made up of many musculoskeletal variables, some variables appear to play a larger role in the contribution of TS and TA. This highlights that while this study has identified a few important musculoskeletal variables that has significantly contributed to TP in each specific group of cricketers, it should be remembered that adequate TP relies on the function of the entire kinetic chain, and therefore no segment should be ignored.

### 5.2 Musculoskeletal correlates to performance

While it was unexpected that the TP would be similar between groups, it was interesting to note that musculoskeletal variables that correlated with throwing performance were different between groups (Figure 5.1). Hip/gluteal strengthening may be warranted for improving TS in the amateur group, which is suggested by the lower, more varied HAS measures compared to the elite group. Moreover, TS in the elite group may benefit more from improving HA ROM compared to the amateur group. While HA ROM was not significantly different between the two groups, it did appear to be slightly lower in the elite group. Since a reduced HA ROM has been associated with increased cumulative load,[141] it could signify that elite players that are usually subjected to increased workloads may need to incorporate some stretching/soft-tissue mobilising to negate a further reduction in HA ROM and subsequent loss in TS. Throwing accuracy has proven to be a more complex measure to understand in the light of musculoskeletal variables alone. A shortened pectoralis minor length or inadequate scapula muscle strength may contribute to altered shoulder mechanics,[133,143] which may negatively affect TA.[34] Therefore, stretching the PML may help maintain a well-functioning shoulder-complex and subsequently improve TA.

These findings highlight that while there may be clear associations between certain musculoskeletal variables and TP, the interaction of these variables within a single thrower's kinetic chain may vary between individuals of different sports and different competitive levels within a single sport. Therefore, while a generalised exercise programme to improve throwing performance may provide some usefulness in improving the musculoskeletal requirements of throwing, optimal throwing performance requires that exercises be based on individual player assessment.

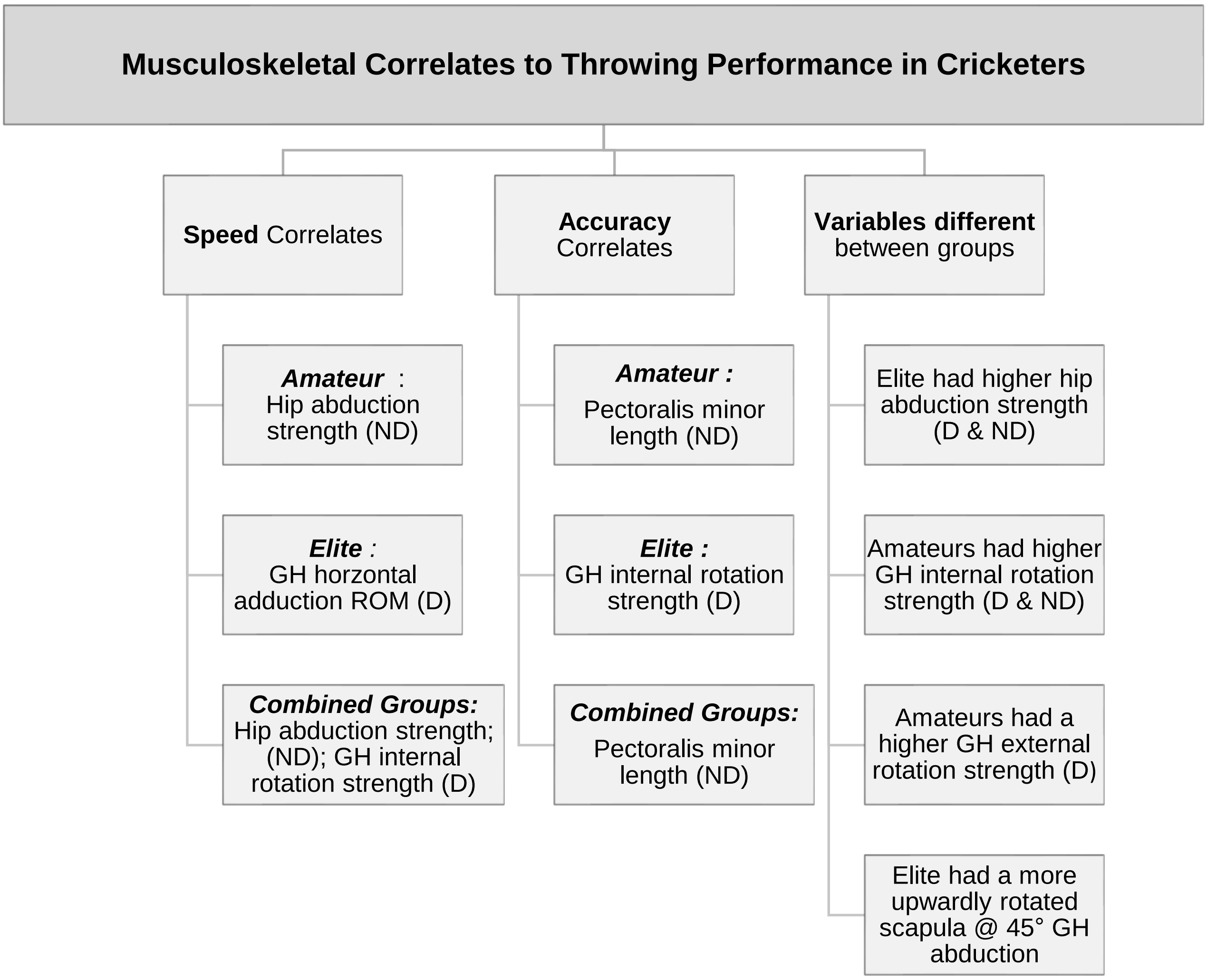



**Figure 5.1** Musculoskeletal correlates to throwing performance in cricketers, and differences between group variables. D Dominant; ND Non-dominant; GH Glenohumeral; ROM Range of Motion.

### 5.3 Study limitations

This study only tested two groups of cricketers at one point in the season (cross-sectional study). The variables tested may change during the season and subsequently affect their influence on TP. Therefore, to ensure optimal TP throughout the season, a musculoskeletal testing session could be repeated during the year to assess the variability of these measures. Although the study excluded participants that reported having shoulder pathology, six elite players and twelve amateur players had one or more positive tests in the pan provocation assessment. While the low specificity and sensitivity of these tests prevents a direct association with injury it may highlight that some players participated with a mild niggle or may have gone on to develop a shoulder injury that session. However, TP was not different for players with and without a positive pain test. While the number of throwing attempts allowed in this study was less than previous literature, this was done to prevent shoulder discomfort in a poor-throwing population. It is possible that a longer but gradual warm up may potentially allow for an improved throwing performance and tolerance to the testing workload.

The protocol used for the throwing performance test in cricket aimed to follow the guidelines set out by Feros et al. (2018).[109] Testing was done indoors to minimize environmental conditions, while this was essential for test reliability, players may have been felt more confident in a more natural outdoor setting. While players were instructed to perform at maximal effort, this was further encouraged by competitiveness between team members. While we didn’t openly display speed results, players often wanted to know their throwing speed and thereafter the following players aimed to reach/beat their team member scores. With that being said, we can’t say with 100 percent certainty that every player performed at his maximum. In order to increase certainty of players’ maximal effort, future studies could look at developing a players’ throwing speed profile (past throwing speed records) which could be used to compare against when assessing player performances. The accuracy test utilized a novel target board design which required minimal equipment and could be analysed quicker than methods involving videography and software analysis. However, due to the scoring system not utilising a continuous variable model, partial scores or fractions of a score could not be awarded. This scoring system may have not been sensitive enough to detect smaller variances in the outcome which could have had a positive effect on the TA score. Further, the non-permittance of a bounce may have negatively affected the accuracy scores, as cricketers sometimes rely on a bounced ball to target the stumps.

## 5.4 FUTURE RESEARCH RECOMMENDATIONS

Future studies investigating TP in cricketers should consider including a randomized controlled trial to confirm whether the variables identified to influence throwing performance can be modified and confirm whether these improvements have a positive influence on TP. Further, potential future studies could also investigate why elite players did not throw better than amateur players

While the performance test in this study required participants to throw directly to the target and did not allow a bounce, future studies should consider awarding a point for a throw that bounces before hitting the target as it may be better suited to cricket-specific throwing. Further, the target board could be increased in size to allow for partial points to be awarded for proximity.

## 5.5 PRACTICAL IMPLICATIONS

This MSc research highlights that throwing speed and accuracy is based on a multitude of factors and is varied between sports as well as between experience levels within the same sport. While there may be some performance-influencing variables like player height and anatomical structures which are non-modifiable, other factors such as muscle strength and throwing biomechanics can be altered to improve TP. This study has identified musculoskeletal variables which if modified, may improve throwing performance in cricketers. A future controlled trial should examine whether an exercise intervention aimed at improving hip abduction strength and horizontal adduction range of motion can improve TS in amateur and elite cricketers respectively. Further it should also investigate whether increasing pectoralis minor length and GH internal rotation strength can improve TA in amateur and elite cricketers respectively. These identified requirements were used to develop an exercise program (Table 5.2) which utilizes minimal equipment and can be easily performed anywhere. While this program has incorporated exercises for both groups together, coaches/trainers may customise the focus of the exercises based on each individual player based on their playing level.

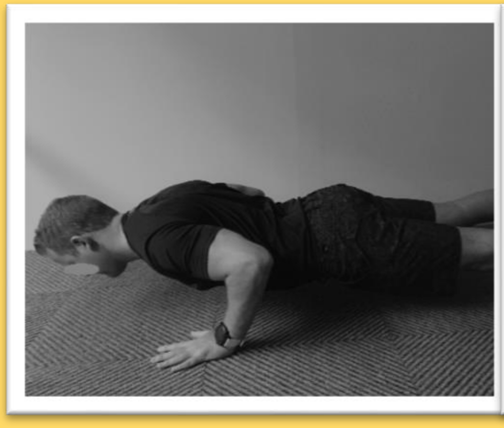
**Table 5.1**. Fantastic 4 + 2: Throwing performance exercises

## 1. PUSH-UP PLUS (INTERNAL ROTATOR STRENGTH)

TARGET MUSCLES: PECTORALIS GROUP/SUBSCAPULARIS/ SERRATUS ANTERIOR

SETS/REPS: 2-3 SETS OF 10-12 (30 SEC REST)

The player does a standard push-up to target the internal-rotator muscles with an added 'plus' on the top to further target the serratus anterior



## 2. OVERHEAD SHOULDER INTERNAL ROTATION
*– WITH RESISTANCE BAND*

TARGET MUSCLES: SUBSCAPULARIS/ PECTORALIS GROUP

SETS/REPS: 2-3 SETS OF 10-12 (30 SEC REST)

The player stands with a split stance, shoulder at 90 abduction and 90 shoulder external rotation with elbow at 90. Player rotates shoulder inward and forward simulating an overhead throw, not just a standard rotation. Return to the starting position should be slow and controlled.

## 3. SINGLE LEG FORWARD REACH WITH RESISTANCE BAND

TARGET MUSCLES: GLUTEUS MEDIUS/ GLUT MAX

SETS/REPS: 2-3 SETS OF 8- 10 (30 SEC REST)

Place a loop resistance band above the knees. The players stands on a single leg with a slightly bent knee and reaches forward with the contralateral arm until the arm is about a ruler length away from the floor. Simultaneously the back leg should extend out laterally, with the glut muscle opposing the resistance of the band,

## 4. SIDE SHUFFLE/ CRAB WALK -WITH RESISTANCE BAND LOOP

TARGET MUSCLES: GLUTEUS MEDIUS

SETS/REPS: 2-3 SETS OF 8 EACH SIDE (30 SEC REST)

The player places the resistance band loop above the ankles or on midway on the shin depending on required effort level. The player slowly steps side-wards overcoming the resistance of the band – Ensure a shoulder-width distance is kept between the feet.

## 5. PECTORALIS MINOR STRETCH

TARGET MUSCLES: PECTORALIS MINOR/MAJOR

SETS/REPS: 2-3 SETS OF 30 SEC EACH SIDE OR TOGETHER

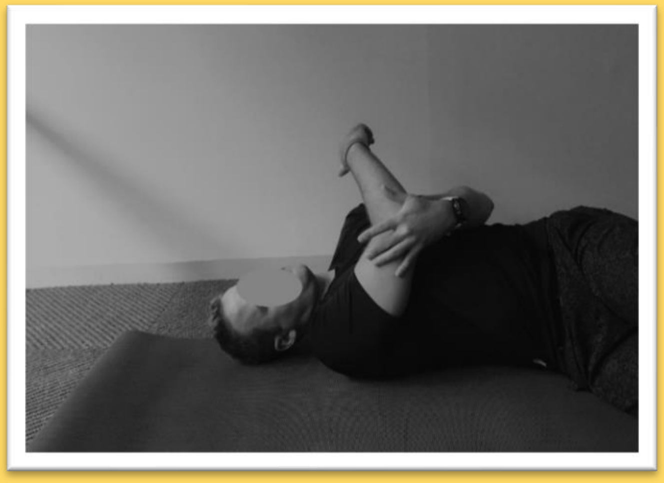
The player stands in the corner of a wall or in a position similar as shown below. The players should be questioned on the effectiveness of the stretch and should adjust arm/body position to ensure the pectoralis minor is being stretched and not the shoulder

## **6.** SHOULDER POSTERIOR CAPSULE STRETCH
(PRESCRIBE ONLY IF NEEDED)

TARGET STRUCTURE: SHOULDER POSTERIOR CAPSULE

SETS/REPS: 2-3 SETS OF 30 SEC HOLDS ON EACH SIDE

The player lies on his side, leaning backwards to ensure the shoulder blade is fixed onto the floor. The player then gently pulls in the upper arm just above the elbow towards the opposite shoulder. A gentle stretch should be felt at the back of the shoulder.



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# APPENDIX I: ETHICAL APPROVAL FOR STUDIES IN THIS THESIS

**UNIVERSITY OF CAPE TOWN**
**Faculty of Health Sciences**
**Human Research Ethics Committee**

**Room E53-46 Old Main Building**
**Groote Schuur Hospital**
**Observatory 7925**
**Telephone** [021] 406 6492
**Email:** sumayah.ariefdien@uct.ac.za
**Website:** www.health.uct.ac.za/fhs/research/humanethics/forms

07 May 2018

**HREC REF: 132/2018**

**Dr J Gray**
Sports Science Institute
Human Biology

Dear Dr Gray

**PROJECT TITLE: THE EFFECTS OF AN EIGHT-WEEK SHOULDER EXERCISE INTERVENTION ON MUSCULOSKELETAL RISK FACTORS, SHOULDER INJURY AND THROWING PERFORMANCE IN SOUTH AFRICAN CRICKET PLAYERS (MASTERS CANDIDATE - MR S AHMED) SUB-STUDY LINKED TO 364/2016**

Thank you for your response letter dated 26 April 2018, addressing the issues raised by the Human Research Ethics Committee (HREC).

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

**Approval is granted for one year until the 30 May 2019.**

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

***We acknowledge that the student: S Ahmed will also be involved in this study.***

**Please quote the HREC REF in all your correspondence.**

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.
Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

HREC 132/2018

# APPENDIX II: INFORMED CONSENT FORM: CHAPTERS 3 AND 4

## Participant Information Sheet

### CAN A MUSCULOSKELETAL SCREENING TEST BE PREDICTIVE OF THROWING PERFORMANCE IN AMATEUR & ELITE LEVEL CRICKETERS?

Dear participant

I a member of the Cricket research group within the Department of Human Biology (Division of Exercise Science and Sports Medicine), University of Cape Town. We will be conducting a study to investigate the relationship of a shoulder screening test and its ability to predict throwing performance amongst elite and club level cricketers.

This study has been granted ethical approval by the Human Research Ethics committee, Faculty of Health Sciences, University of Cape Town (HREC **132/2018**:)

Please take time to thoroughly read this form before signing.

Prior to your inclusion within this study, you will be required to complete and sign this form.

***Why is this study being done?***

Throwing performance is a vital component of fielding. Although batting and bowling performance has been significantly researched, the same can’t be said for throwing performance (from fielding) in cricketers. Therefore, this study sets out to better understand what musculoskeletal factors are important for predicting and possibly improving throwing performance.

***Why am I being asked to take part in this study?***

You are being asked because you are a competitive cricketer and your training is consistent and more structured than other players at other levels. Therefore, there are fewer variables that may interfere with the outcome of this study. This will help ensure we can accurately describe the true effects of the exercise intervention on injury reduction.

***How many people will take part in this study?***

60 competitive cricketers who are part of the cricket set-up for the 2018/2019 season was/will be asked to participate in this study.

***How long will this study last?***

You will not be required to participate in anything further than today's session

**What criteria make you eligible to take part in the study?**

You are eligible to take part in this study if you fulfil the following criteria:

- *18 years of age or older*
- *Form part of an elite or sub-elite 2018/2019 season*
- *Participate in a minimum of one format (Four day, One day or T20) cricket matches throughout the 2018/2019 season*
- *You are **not** currently injured/or receiving treatment/rehabilitation for any injury*

***What will I be asked to do if I decide to take part in the study?***

You will be asked to participate in shoulder pre-season screening test (details explained below) at your facility. Please be informed that you will be required to dress in shorts and a comfortable T-shirt. The testing protocol for all participants is described below.

1. **Questionnaire**.
   You will be required to complete a questionnaire regarding your shoulder function related to activities of daily living and sport.

2. **Anthropometric measurements**
   **a. Height**

   Your height will be measured by you standing barefoot in your shorts, with your heels and back flush against a wall.

   **b. Body Mass**

   Your body mass will be recorded by you standing barefoot in your shorts on a scale.

3. **Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score.**
   This is a one-page questionnaire and you will be required to complete all sections. This questionnaire will take you approximately five minutes to complete.

4. **Specific clinical musculoskeletal tests**
   The following clinical tests will be performed on your shoulder and hip in a variety of positions i.e. standing, sitting or lying on your back)
   a. **Impingement tests/Pain provocation test** (used to assess the presence of shoulder pain by a yes/no answer)

i. Hawkins-Kennedy Test

ii. Jobe's Test

**b. Measurement of Passive Shoulder Range of motion for internal and external rotation**

**c. Measurement of upward scapular rotation**

**d. Measurement of posterior shoulder tightness**

**e. Latissimus Dorsi muscle tightness**

**f. Isometric muscle strength of internal and external shoulder rotator muscles**

**g. Isometric strength of scapular stabilization muscles**

i. Serratus Anterior muscle

ii. Upper Trapezius muscle

iii. Lower Trapezius muscle

**h. Isometric strength of the Gluteus Medius muscle (Hip abduction strength)**

**i. Closed Kinetic Chain Upper Extremity Stability Test**

**j. Measurement of maximal throwing speed'**

**k. Measurement of throwing accuracy**

***What are the risks of participating in this study?***

- Although the greatest care will be taken when performing the clinical evaluation, it is possible that some participants may experience a slight temporary increase in shoulder pain when an already painful shoulder is examined. However, testing will be discontinued if the increase in pain becomes sustained during the session.

***Are there any benefits of me taking part in this study?***

You will receive information regarding your body anthropometric measurements such as height and weight. Unfortunately, there is no monetary compensation provided for participating in this study. By participating in this study, you are helping in the development of an intervention aimed at improving throwing performance and possibly reducing the risk of developing shoulder injury in the future. Further, by learning about which exercises may be beneficial for you, your throwing performance i.e. throwing speed and throwing accuracy may also improve. At the completion of the investigation you will receive a summary of the study results.

***What happens if I choose not to participate in the study?***

Your participation in this study is completely voluntary. You have the right to withdraw from the study at any time without providing reasons or face any repercussions. Your decision not to participate in this study will not affect your position/selection in the team in any way and will also remain undisclosed to the team management, coach or team staff.

***What will happen when the study is over?***

At the conclusion of the study, the data collected will be published (anonymity always maintained) in respective medical journals and made available to you, as well as your respective coach and/or other management staff. Raw data will be kept in a locked filing cabinet for a period of five years, after which all information will be shredded.

***Who will see the information which is collected about you during the study?***

Only the principle investigator and supervisors (details listed below) will have access to your information during this study. All participant information will be kept confidential by ensuring the use of a coding system. Each participant will be allocated a specific code ensuring anonymity, the details of these participant codes and participant information will be held private and confidential and stored in a locked filing cabinet.

***What happens if I get hurt taking part in this study?***

This research study is covered by an insurance policy taken out by the University of Cape Town if you suffer a bodily injury because you are taking part in the study. The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the SA Good Clinical Practice Guidelines 2006. The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the study investigator for a copy of these guidelines.

The insurer will *not* pay for harm if, during the study, you:

- Use medicines or other substances that are not allowed
- Do not follow the study investigators' instructions
- Do not take reasonable care of yourself

If you are harmed and the insurer pays for the necessary medical costs, usually you will be asked to accept that insurance payment as full settlement of the claim for medical costs. However, accepting this offer of insurance cover does not mean you give up your right to make a separate claim for other losses based on negligence, in a South African court.

It is important to follow the study investigators instructions and to report straightaway if you experience any adverse effect from the exercises.

***Who do I speak to (or contact) if I have questions about the study?***

If at any time you have any questions or concerns about this study, please feel free to contact me or any of the individuals listed below. Please be assured that all enquiries will remain private and confidential.


**Student Investigator: Mr Safwaan Ahmed**

Physical Address: Division of Exercise Science and Sports Medicine,
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**Principal Investigator: Dr Janine Gray**

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The **UCT's Faculty of Health Sciences Human Research Ethics Committee** can be contacted on **021 406 6338** (Prof. Marc Blockman, chair of the committee) in case you have any ethical concerns or questions about your rights or welfare as a participant on this research study.

Please note that UCT does offer a no-fault insurance that will cover all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury according to the Association of the British Pharmaceutical industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence

## PARTICIPANT CONSENT FORM

### CAN A MUSCULOSKELETAL SCREENING TEST BE PREDICTIVE OF THROWING PERFORMANCE IN AMATEUR & ELITE LEVEL CRICKETERS?

I, the undersigned, have been fully informed about the study entitled **“A Musculoskeletal Screening Test Be Predictive Of Throwing Performance In Amateur & Elite Level Cricketers ?** to be conducted by researchers from the UCT Research Unit for Exercise Science and Sports Medicine within the Department of Human Biology, Faculty of Health Sciences, University of Cape Town.

***Please tick the box below confirming that you consent to participating in the following:***

I consent to participating in the screening testing sessions as well as the throwing performance testing as described above in the participant information section. ☐

The protocol for this study has been described in the Participant Information document and I have had an opportunity to ask questions about the procedures and the results of the tests to be performed.

I have read and understood all the risks inherent to participating in this trial. I understand that all information collected during this study will be treated confidentially, be used only for scientific research purposes and that my name and personal particulars will not be released under any circumstances.

I am aware that I may withdraw from the study at any time if I so wish, without providing an explanation. I understand that I will receive, where applicable, feedback pertaining to the results of the screening tests.

I agree to participate in the study.

| ______________________ | ______________________ | ______________ |
|---|---|---|
| Signature of Volunteer | Full name (please print) | Date |

# APPENDIX III: DEMOGRAPHIC DATA AND ANTHROPOMETRIC COLLECTION FORM

PARTICIPANT CODE: _____________ DATE: ____________

## 1. PERSONAL DATA

| | |
|---|---|
| NAME | |
| SURNAME | |
| DATE OF BIRTH (Y/M/D) | |
| AGE | |
| CURRENT TEAM | |
| HIGHEST TEAM ACHIEVED | |
| PRIMARY DISCIPINE (bat/bo) | |
| HANDEDNESS (L/R) | |
| PLAYING EXPERIENCE YEARS (SPECIFY PRO/AMATEUR) | PROFESSIONAL:<br>AMATEUR: |

## 2. CONTACT DETAILS

The following information is needed for player feedback during the study as well as feedback to the players upon completion of the study

| | |
|---|---|
| Email address | |
| Contact Number | |

## 3. BODY MEASUREMENTS

| | |
|---|---|
| Height (cm) | |
| Weight (kg) | |

## 4. GENERAL HEALTH STATUS

Do you suffer from any of the following? If yes, please specify frequency (e.g. twice a week) as well as medication you make use of, if applicable.

| Condition | YES | NO | Frequency | Medication |
|---|---|---|---|---|
| Asthma | | | | |
| Diabetes | | | | |
| Hypertension | | | | |
| Angina | | | | |
| Epilepsy | | | | |
| Dizziness | | | | |
| Migraines | | | | |
| Nausea | | | | |

## 5. INJURY HISTORY

Please indicate if you've sustained any of the following injuries, please mark an 'X' in the appropriate column. If applicable, please follow through the entire line. If no, ignore without indicating.

| Injury | Last 12 months | Past 5 years | Lifetime occurrence | Side | | Is the injury still present? | |
|---|---|---|---|---|---|---|---|
| | | | | Left | Right | Yes | No |
| Whiplash | | | | | | | |
| Neck Injury | | | | | | | |
| Shoulder muscle tear | | | | | | | |
| Shoulder impingement | | | | | | | |
| Shoulder labral tear | | | | | | | |
| Other shoulder injuries | | | | | | | |
| Upper arm muscle tear | | | | | | | |
| Pain radiating down either arm | | | | | | | |
| Upper back pain | | | | | | | |
| Lower back pain | | | | | | | |
| "Tennis elbow" | | | | | | | |
| Other elbow injuries | | | | | | | |

## 6. Training History

Please indicate your **<u>average</u>** training frequency and type **<u>per week</u>** by marking 'X' in the appropriate boxes.

| Training Type | 0-30 min | 30 min-1hr | 1 - 2 hr. | 3 - 5 hr. | 5 - 7 hr. | > 7 hr. |
|---|---|---|---|---|---|---|
| Nets- Batting | | | | | | |
| Nets- Bowling | | | | | | |
| Fielding | | | | | | |
| Fitness | | | | | | |
| Strength Training | | | | | | |

# APPENDIX IV: KERLAN-JOBE ORTHOPAEDIC CLINIC (KJOC) SHOULDER AND ELBOW SCORE

Subject Code: _______________

***Please answer the following questions related to your history of injuries to YOUR ARM ONLY:***

1. Is your arm currently injured? YES NO
2. Are you currently active in your sport? YES NO
3. Have you missed game or practice time in the last year due to an injury to your shoulder or elbow? YES NO
4. Have you been diagnosed with an injury to your shoulder or elbow other than a strain or sprain? YES NO
5. Have you received treatment for an injury to your shoulder or elbow?
   YES NO

   If yes, what was the treatment? (Check all that apply)

   - ☐ Rest
   - ☐ Therapy
   - ☐ Surgery (please describe)________________________

***Please describe your level of competition in your current sport:*** (Use Protea, Franchise, Club, and Varsity as choices)

6. What is the highest level of competition you've participated at? __________________
7. What is your current level of competition? ___________________________________
8. If your current level of competition is not the same as your highest level, do you feel it is due to an injury to your arm? YES
   NO

Please check ONE category only that best describes your current status:

- ☐ Playing without any arm trouble
- ☐ Playing, but with arm trouble
- ☐ Not playing due to arm trouble

***Instructions to athletes:***

***The following questions concern your physical functioning during game and practice conditions. Unless otherwise specified, all questions relate to your shoulder or elbow. Please answer with an X along the horizontal line that corresponds to your current level.***

1. How difficult is it for you to get loose or warm prior to competition or practice?

*Never feel loose during games or practice* — *Normal warm-up time*

2. How much pain do you experience in your shoulder or elbow?

*Pain at rest* — *No pain with competition*

3. How much weakness and/or fatigue (i.e.: loss of strength) do you experience in your shoulder or elbow?

*Weakness or fatigue preventing any competition* — *No weakness, normal competition fatigue*

4. How unstable does your shoulder or elbow feel during competition?

*"Popping out" routinely* — *No instability*

5. How much have arm problems affected your relationship with your coaches, management and agents?

*Left team, traded or waived, lost contract or scholarship* — *Not at all*

***The following questions refer to your level of competition in your sport. Please answer with an X along the horizontal line that corresponds to your current level.***

6. How much have you had to change your throwing motion due to your arm?

←——————————————————————→

*Completely changed, don't perform motion anymore* *No change in motion*

7. How much has your throwing velocity and/or power suffered due to your arm?

←——————————————————————→

*Lost all throwing power* *No change in velocity/power*

8. What limitation do you have in endurance in competition due to your arm?

←——————————————————————→

*Significant limitation (Stopped bowling or changed field placing)* *No endurance limitation in competition*

9. How much has your control (bowling, throwing) suffered due to your arm?

←——————————————————————→

*Unpredictable control* *No loss of control*

10. How much do you feel your arm affects your current level of competition in your sport (i.e.: is your arm holding you back from being at your full potential)?

←——————————————————————→

*Cannot compete, has to switch sports* *Desired level of competition*

# APPENDIX VI: DETAILED METHODOLOGY FOR MUSCULOSKELETAL SCREENING AND THROWING PERFORMANCE TESTS

## 1. Methods

### 1.1 Participants

Prior to recruitment, ethical approval was obtained from the Human Ethics Research Committee, Faculty of Health Sciences, University of Cape Town on the on the 07$^{th}$ May 2018, HREC 132/2018 (Appendix I). The University of the Western Cape cricket team and adult amateur cricket teams in the Western Cape were approached for participation in our study.

A presentation explaining the aims, as well as the benefits and risks of taking part in the study was given to the players, coaches and management. It was emphasized to the players that participation was completely voluntary, and that non-participation would not affect team selection or position in the team whatsoever. Players that volunteered in the study were required to complete an informed consent form (Appendix II), demographic data, training experience & injury history form (Appendix III), as well a shoulder function questionnaire (Appendix IV). Participants were allocated a code identification number to be used for the duration of the study, ensuring anonymity.

### 1.2 Inclusion and exclusion criteria

Participants were included if they were aged 18 and over and formed part of the franchise & amateur teams for the 2018/2019 cricket season. Any player that had an injury was excluded from the study. Any player that received treatment for an injury was also excluded as the rehabilitation received from a physiotherapist or other practitioner would've been a confounding variable for the study. All participants completed both the musculoskeletal screening battery as well as the throwing performance (speed and accuracy) tests.

### 1.3 Sample size determination

Based on previous studies, the three most common musculoskeletal variables assessed in overhead athletes were scapular dyskinesis; shoulder range of motion; shoulder external rotation strength[31,37,81,144,145]. From these three variables, shoulder external rotation strength has shown to require the largest sample size in order to detect any significant ($p < 0.05$) difference. This is based on a current study (364/2016) which investigated similar variables. The calculation was as follows: Required sample size for strength of GH internal and external rotators was calculated using a small meaningful difference of two, and a standard deviation of three (effect size $d = 0.7$). With statistical significance accepted as $p < 0.05$, a group of 29 participants will provide 80% statistical power for strength of GH internal and external rotators, respectively."

Since our study will have both an amateur and elite group, the total number of participants required will be doubled, therefore 58 participants (29 in each group) is deemed necessary to detect a significant difference.

## 2. Study Procedure

### 2.1 Informed consent

The informed consent form (Appendix II) explained that participation in the study was voluntary and that ethical approval for this study was granted. The testing procedures, the risk, benefits and significance of the study were thoroughly explained. The participants were informed that they had the right to withdraw from the study at any time, and that confidentiality would be maintained.

### 2.2 Demographic information

Participants were required to complete a questionnaire to obtain basic demographic data, training and competition history and injury history (Appendix III).

### 2.3 Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow Score Questionnaire

Shoulder function was subjectively assessed using the KJOC questionnaire (Appendix IV). The questionnaire is divided into three sections including function and athletic performance (four questions), symptoms related to the upper limb (five questions) and interpersonal relationships related to performance (one question). Each question uses a Visual Analog Scale (VAS) where, the extreme left indicates the lowest level of function or performance and greatest severity of the symptom assessed. The extreme right of the scale indicates the highest level of function or performance and lowest possible severity of symptom assessed.

This questionnaire has been validated and shown to be more specific than other shoulder pain/disability score questionnaires. Alberta et al[119] found the KJOC Score to be both a reliable (ICC = 0.88) and a valid (r = 0.84-0.86) measure of shoulder and elbow function in overhead athletes

### 2.4 Musculoskeletal tests

#### 2.4.1 Impingement tests: Hawkins-Kennedy

**a) Hawkins-Kennedy:** The participant stood with his shoulder and elbow flexed to 90º. The examiner ensured the shoulder stays in 90° flexion by placing his arm under the participant's arm being tested, resting his palm on the opposite shoulder of the participant. The participant's shoulder was then passively moved into internal rotation by the therapist holding onto the distal forearm. Sensitivity 79%, Specificity : 59%[146]. Reliability : (k=0.91 agreement)[147] and (ICC 0.93-0.97)[148]

**b) Jobes:** The participant stood with both shoulders elevated to 90º in the scapula plane and internally rotated to maximum (thumbs down/empty can). The examiner then placed a downward pressure over the participant's lower arm and resisted further elevation. The test was repeated in the full can position (thumbs up) to further investigate possible rotator cuff pathology. Sensitivity 50 % & Specificity 87%[149]. Reliability : (k=0.94 agreement)[148]

### 2.4.2 Passive internal & external rotation shoulder ROM

Shoulder Internal and external range of motion was measured using a hand-held goniometer/ digital inclinometer. This method has been found to have a high intra-rater reliability by Sabari et al. (1998)[150] . The participant lay supine on a plinth with the shoulder in 90° abduction (frontal plane) and the elbow flexed to 90° (sagittal plane). A towel was be placed under the upper arm to ensure the shoulder was supported in a neutral and horizontal position. The fixed arm of the goniometer was kept perpendicular to the plinth/ground and the olecranon process acted as the fulcrum, with the moving arm positioned parallel to the shaft of the ulna. The arm of the participant was moved by the examiner into the maximum internal rotation ROM (Figure VI.1). Care was taken to stabilize the scapula to ensure that scapula movement did not contribute to the internal rotation range of movement. This was also done for external ROM (Figure VI.2) following the same goniometer placement as above, the participants arm was moved into maximal external rotation. The average of two measures was taken on both the left and right arms.

**Figure VI.1**. GH Internal rotation ROM

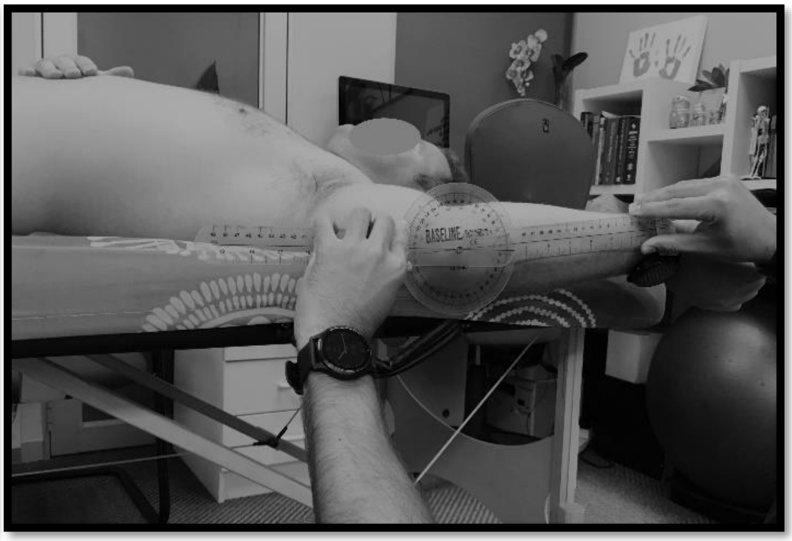

**Figure VI.2** GH External rotation ROM

### 2.4.3 Posterior shoulder tightness

Posterior shoulder tightness was be measured via horizontal adduction of the shoulder. Good intra-rater reliability (ICC = 0.91) and construct validity has been established for this method[128]. The participant lay supine on plinth with arms to the sides in full elbow extension and neutral shoulder rotation. An inclinometer was secured to the arm, perpendicular to the shaft of the humerus, just above the lateral epicondyle using a Velcro strap. The starting point of the test began at 90° shoulder and 90° elbow flexion. At this point the inclinometer was set to 0°. To begin, participants were asked to maximally retract their scapula which was then stabilized by the thenar eminence of the examiner against the lateral border of the scapula. The investigator then passively horizontally adducted the humerus to the end range of motion as shown in (Figure VI.3) below. At this point the inclinometer reading was recorded for maximal horizontal adduction. The average value of two measurements was recorded for posterior shoulder tightness bi-laterally. The non-dominant arm was be measured prior to the dominant arm.

**Figure VI.3** Shoulder horizontal adduction ROM

**2.4.4 Latissimus Dorsi tightness**

Latissimus Dorsi tightness was measured as described by Kendall et.al.[151] . The Participant lay supine with knees flexed to 90° and feet on the plinth. The participant was instructed to actively contract the abdominal muscles and to place the lumbar spine flat on the plinth, breathing normally. The participant's arm was then passively moved into maximal shoulder flexion toward the plinth. No movement of the upper or lower back was allowed. The shoulder flexion angle was measured using a goniometer as shown in (Figure VI.4) below.


**Figure VI.4** Latissimus dorsi flexibility

### 2.4.5 External rotation strength & internal rotation strength

Glenohumeral internal and external rotation strength was measured with the participant seated with his elbow placed on the plinth with 90° GH abduction and 90° GH external rotation as described by Hayes et al[123] and shown in (Figure VI.4 & VI.5) below. The investigator stabilized the medial aspect of the distal humerus with the non-testing hand, and the HHD centred on the dorsal aspect of the distal forearm. The investigator applied an opposing force to the participants hand i.e. pushed the arm towards external rotation for an internal rotation measure and into internal rotation for the external rotation measure. Pressure was applied for 5 seconds to ensure the force output of the participant was adequately matched. For internal rotation strength, the investigator stabilized the lateral aspect of the distal humerus and the HHD was centred on the volar aspect of the forearm. The average of two measures was used.

**Figure VI.4** GH Internal rotation strength

**Figure VI.5** GH External rotation strength

### 2.4.6 Scapular muscle strength

Muscle strength of the three scapular muscle stabilizers i.e. serratus anterior, upper trapezius and lower trapezius were measured using a Hand-held dynamometer (HHD). The average of two measures was recorded as the strength value for each of the muscles. Measurements of the following three muscles were done as described by Cools et al. (2010)[42] who found these tests to be reliable and acceptable for clinical and research use. These tests were also found to be reliable by Celik et al. (2012)[152] . Reliability of tests range: ICC (.77- .99)[152]

#### 2.4.6.1 Serratus anterior muscle strength

The participant was positioned supine with his arm fully extended and positioned in 90° shoulder flexion. The HHD was then placed in the palm of the participants extended arm. A downward force (toward the plinth) was applied by the examiner onto the HHD while the participant was asked to perform scapular protraction (scapula punch) against the investigators' resistance as shown in (Figure VI.6) below.

**Figure VI.6** Serratus anterior muscle strength

**2.4.6.2 Upper trapezius muscle strength:**

The participant was seated with arms to the side. The examiner stood behind the participant and placed the HHD over the superior aspect of the scapula. The participant was instructed to maximally elevate the scapula towards the ceiling against the investigators downward applied resistance of the HHD as shown in (Figure VI.7) below.

**Figure VI.7** Upper trapezius strength

#### 2.4.6.3 Lower trapezius muscle strength

The participant lied prone on a plinth with one shoulder abducted to 145° of abduction and full shoulder external rotation (thumbs up position). The examiner then placed the HHD on the distal 1/3 of the lateral aspect of the radius. Participants were instructed to raise their arm up towards the ceiling against the downward force applied by the examiner with the HHD as shown in (Figure VI.8).

**Figure VI.8** Lower trapezius strength

### 2.5 Hip abduction (gluteus medius) muscle strength: side lying

Gluteus Medius (Hip abduction strength) was measured with the participant in a side-lying position. This method has been described and validated by Widler et al. (2009)[124]. Participants were positioned on their sides with the contralateral (bottom) hip and knee bent to 30° flexion for comfort and stability. The tested (top) leg was be kept in full knee extension and 10° of abduction. Participants kept their arms folded onto their chests to ensure they did not use the upper body to help stabilize or assist with the movement. Participants were instructed to perform a maximal contraction side leg raise (abduction) against the downward resistance of the hand-held dynamometer (HDD) held by the examiner as shown in (Figure VI.9) below. The HHD was placed 5 cm proximal to the lateral femoral epicondyle. The non-dominant leg was measured prior to the dominant leg. Each leg was be measured twice and an average measurement for isometric hip abduction strength will be recorded. Good intra-rater reliability (ICC = 0.90) and construct validity has been established for this method of measuring isometric gluteus medius muscle strength[124].


**Figure VI.9** Hip abduction strength

**2.6 Scapular upward rotation**

Upward scapula rotation was measured using the protocol described by Watson et al.(2005)[153] However, a digital inclinometer was used instead of a Plurimeter. Participants stood comfortably with their feet positioned shoulder width apart, arms at the side and elbows extended. An inclinometer was secured perpendicularly to the shaft of the humerus, just above the lateral epicondyle using a Velcro strap and was positioned so that 0° corresponded with the vertical, i.e. perpendicular to the floor. Participants were instructed to abduct their arm and asked to stop at 45°, 90° and 135°. Scapula upward rotation was be measured at rest, and at each of these abduction positions by aligning the base of a second inclinometer to the spine of the scapula, manually as shown in (Figure VI.10) below. This method of assessing scapula upward rotation has demonstrated good to excellent intra-rater reliability (ICC = 0.89 – 0.96) and good validity[154].

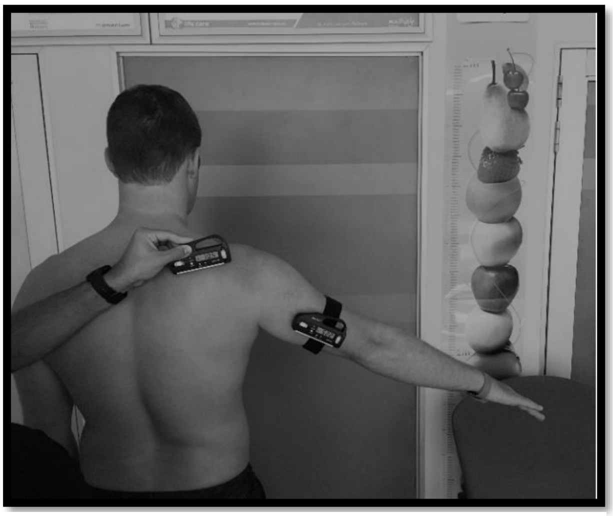

**Figure VI.10** Scapula upward rotation measurement

**2.7 CKCUEST**

The CKCUES (closed kinetic chain exercise upper extremity stability) test has been used to assess the stability of the shoulder. The reliability of this test is excellent (ICC= 0.97) [120]. Its validity has also been shown to be moderate to high. The correlations between the CKCUES test and maximum grip strength (r = 0.78 – 0.79), and the peak torque of shoulder internal/external rotation (r = 0.87 – 0.94) is high[120]. The CKCUES test will be performed as described by Lee et al. (2015) [120].

Two strips of athletic tape with a width of about 3.8 cm was placed parallel to each other 91.4 cm apart, as measured by a standard tape measure on a tiled floor. The participant started with one hand on each piece of tape in the pushup position. The participant was instructed to use one hand from the starting position to reach across his body and touch the piece of tape lying under the opposing hand. After touching the tape line, his hand had to be returned to the original starting position. This had to be repeated using alternate hands as many times as possible in 15 sec. Touches were counted every time the hand touched the opposite tape. A warm-up trial was followed by three trials of the test with a rest period of 45 seconds between trials will be performed. The average of the three trials was be used in the data analysis.

### 3. Throwing performance testing

Throwing performance is a measure of both the speed and accuracy of a throw. The protocols for each measure is described below. All testing was done indoors in a biomechanics lab as well as an indoor-nets training facility with adequate lighting to minimize external environmental conditions such as wind, barometric pressure, relative humidity. While these are factors that are undeniably present in the actual game, they negatively impact the testing reliability of the performance measures[109].

### 3.1 Throwing speed

Throwing Speed: Participants performed an individual warm-up which consisted of self-selected arm movements (shoulder arc rolls, dynamic stretches) followed by a standardized throwing warm-up routine: ten sub-maximal overhead throws at an increasing degree of intensity (5 x 50% effort, 3 x 70%, 2 x 90%) with a cricket ball. For the test, participants stood 20 metres away from the target (Figure VI.12) below. They were instructed to throw a regulation size cricket ball (approx. 7.2 cm diameter) and weight (156g) toward the target with no bounce using a forward stride from a stationary position (Figure VI.11). Participants performed two throws at maximal intensity and the highest speed was recorded as the participant's maximum throwing speed (MTS). It was emphasized that maximum speed was the aim of the first set of two throws. This MTS value was then used as a benchmark to 'validate' the subsequent three throws which focused on accuracy. TS was measured using a radar gun (Stalker Pro, Applied Concepts, Inc. Texas, USA). The tester stood directly behind the participant and aimed the gun at the height of the participant's throwing hand. Recording commenced three seconds prior to ball release.

### 3.2 Throwing accuracy

Throwing Accuracy: Participants stood 20 metres away, facing the target board, which was designed using the dimensions of a standard stump set up. Participants were required to execute five overhead throws at more than 80% of the recorded MTS as accurately as possible. All players threw within their accepted range. A simple scoring technique, analogous to that used in darts, was used and points were awarded according to the site of ball contact on the target. Points were awarded as follows, (1) Three points for ball contact on the green centre circle, coinciding with the middle of the centre stump. (2) Two points for ball contact on the inner dark-blue rectangle, coinciding with the dimensions of the width and height of a standard wicket set. (3) as shown below in (Figure VI.13). One point for ball contact on the outer light-blue rectangle, this was technically a miss off the wicket, however a point was awarded due to proximity. Zero points were awarded if the target was completely missed.

**Figure VI.11** Indoor testing facility


**Figure VI.12** 20 metre distance from target

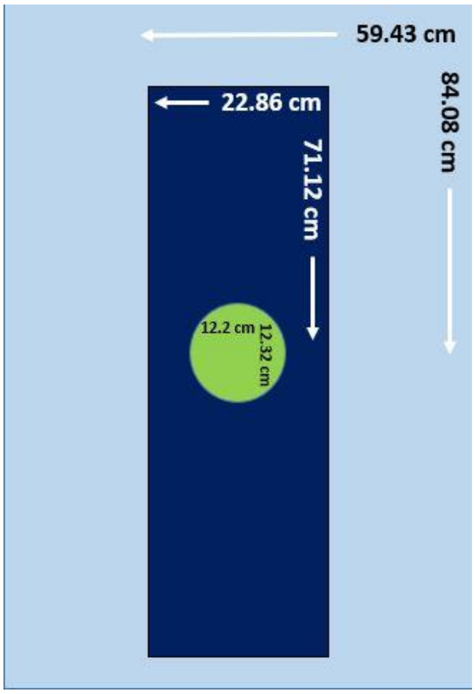


**Figure VI.13** Target board with size dimensions

# APPENDIX VII: DESCRIPTIVE RESULTS FOR ALL VARIABLES

| Variable Tested | Side | Max. Speed | | Accuracy | |
|---|---|---|---|---|---|
| | | r | p | r | p |
| 1. Scapular Upward Rotation at rest (°) | D | 0.057 | (0.756) | -0.57 | (0.758) |
| | ND | 0.105 | (0.568) | -0.107 | (0.561) |
| 2. Scapular Upward Rotation at 45° (°) | D | -0.239 | (0.187) | -0.343 | (0.054) |
| | ND | -0.078 | (0.670) | -0.036 | (0.847) |
| 3. Scapular Upward Rotation at 90° (°) | D | -0.095 | (0.605) | -0.160 | (0.381) |
| | ND | -0.022 | (0.905) | -0.118 | (0.521) |
| 4. Scapular Upward Rotation at 135° (°) | D | -0.029 | (0.873) | -0.194 | (0.288) |
| | ND | -0.154 | (0.401) | -0.295 | (0.101) |
| 5. Internal Rotation ROM (°) | D | 0.172 | (0.347) | -0.201 | (0.269) |
| | ND | 0.036 | (0.843) | -0.106 | (0.564) |
| 6. External Rotation ROM (°) | D | -0.019 | (0.918) | -0.055 | (0.764) |
| | ND | 0.087 | (0.635) | -0.196 | (0.283) |
| 7. Horizontal Adduction ROM (°) | D | -0.029 | (0.873) | 0.195 | (0.284) |
| | ND | -0.067 | (0.716) | 0.177 | (0.333) |
| 8. Latissimus Dorsi Flexibility (°) | D | 0.131 | (0.482) | 0.223 | (0.228) |
| | ND | 0.211 | (0.253) | 0.129 | (0.489) |
| 9. Pectoralis Minor Length (cm) | D | -0.125 | (0.496) | 0.303 | (0.091) |
| | ND | -0.151 | (0.409) | 0.466 | (0.007) * |
| 10. External Rotation Strength (N) | D | 0.473 | (0.006) ** | -0.154 | (0.400) |
| | ND | 0.400 | (0.023) * | 0.019 | (0.916) |
| 11. Internal Rotation Strength (N) | D | 0.463 | (0.008) ** | -0.029 | (0.874) |
| | ND | 0.379 | (0.033) * | -0.037 | (0.842) |
| 12. Serratus Anterior Strength (N) | D | 0.129 | (0.483) | 0.104 | (0.572) |
| | ND | 0.216 | (0.234) | 0.095 | (0.605) |
| 13. Upper Trapezius Strength (N) | D | 0.265 | (0.143) | -0.452 | (0.009) * |
| | ND | 0.101 | (0.582) | -0.312 | (0.082) |
| 14. Lower Trapezius Strength (N) | D | 0.232 | (0.201) | -0.387 | (0.029) * |
| | ND | 0.239 | (0.188) | -0.178 | (0.331) |
| 15. Hip Abduction Strength (N) | D | 0.315 | (0.080) | -0.015 | (0.936) |
| | ND | 0.395 | (0.025) * | -0.095 | (0.603) |
| 16. Closed KCUE Stability Test (N) | - | 0.165 | (0.368) | -0.262 | (0.148) |
| | | - | - | - | - |
| 17. KJOC Questionnaire score (/100) | - | -0.15 | (0.938) | -0.50 | (0.797) |

*Multivariate correlation matrix for all variables tested. * p < 0.05; ** p< 0.01. CM Centimetres; N Newtons;* ***(°)*** *degrees; ROM Range of movement; D Dominant; ND Non-dominant*