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# A Kinematic Analysis of the star excursion balance test and its ability to predict Injury

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# A Kinematic Analysis of the Star Excursion Balance Test and its Ability to Predict Injury

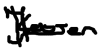
Taskeen Hoosen

‘A Dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Physiotherapy”

Johannesburg 2018

**DECLARATION**

I Taskeen Hoosen declare that this Thesis/Dissertation is my own work. It is being submitted for the Degree of Masters of Science in Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted for any other degree or examination at any other University.



_____

(Signature of candidate)

This 8th day of June 2018 in Johannesburg

This dissertation is dedicated to my parents, Feroze and Fazila Hoosen

## ABSTRACT

### Background

Recent studies have shown an increase in incidence and prevalence of injury in cricket. Successful injury prevention requires ongoing injury surveillance and injury screening for early intervention of at risk players.

### Objective

The aims of this study are to determine if the Star Excursion Balance Test (SEBT) and 3D kinematics of the lower limb are predictive of lower limb injury in cricket and to determine the lower limb kinematics during the SEBT.

### Method

This is an observational, longitudinal cohort study. Twenty-four provincial level adult male cricket players participated in this study. Pre-season questionnaires were completed for baseline information and to determine eligibility. Participants performed the SEBT while being analysed by Optitrack 3D kinematics cameras and software. Injury surveillance took place during the 2015/2016 cricket season with injury monitoring questionnaires. Statistical test including correlations, tests for significance, a receiver operating curve and regression analyses were all performed, in order to establish if there is a relationship between the SEBT, 3D kinematics and injury prediction.

### Results

Twenty-two participants with a mean age of 20.2 (SD= 3.8) completed the study. 50% sustained injuries; 59% of which were in the lower limb. Lumbar injuries were the most prevalent. There were no statistically significant results between the injured and non-injured groups during the SEBT. Regression analysis revealed decreased hip flexion angles of the stance leg in the anterior direction accurately predict 76% likelihood of injury. The ankle abduction angle was statistically significant when comparing injured and non-injured participants in the anterior direction of both limbs (Dominant p= 0.035; Non-Dominant p= 0.022) and in the postero-lateral direction of the dominant limb (p= 0.035). Knee abduction angles were statistically significant when comparing injured and non-injured participants in the postero-medial direction in the non-dominant limb (p= 0.008).

**Conclusion**

The SEBT in its simplest form did not predict an increased risk of injury. Supplemented with the hip, knee and ankle angular kinematics, the findings of the SEBT were able to predict injury.

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## LIST OF ABBREVATIONS

| | |
|---|---|
| 3D | Three-dimensional |
| SEBT | Star Excursion Balance Test |
| GPS | Global Positioning System |
| ODI | One Day International |
| ASIS | Anterior Superior Iliac Spine |
| PSIS | Posterior Superior Iliac Spine |
| SD | Standard Deviation |
| PFPS | Patellofemoral Pain Syndrome |
| AUC | Area under the curve |
| ACL | Anterior Cruciate ligament |
| CI | Confidence Interval |

## LIST OF DEFINITIONS

**Injury:** ‘any musculoskeletal condition that occurred during practice or a match, which caused the player to either quit that activity or miss at least the next game or practice session’ (Olivier et al, 2015)

**Incidence of injury:** The number of injuries occurring over a period of time (Orchard et al, 2016)

**Prevalence of injury:** The average percentage of players who are not available for match selection, incidence (Orchard et al, 2016)

**Recovery:** Is defined as when medical staff have determined that the player has returned to match availability, regardless of whether a match is scheduled for that day or not’ Orchard et al, (2016, p. 1247),.

**Recurrent injury:** An injury of the same type, which reoccurs in the same season (surveillance year) after it has been defined as recovered (Orchard et al, 2016).

**Biomechanics:** The study of mechanical laws and their application to living organisms, particularly the human body and its movement (Richards, 2008).

**Postural control**: Is the inherent ability to establish and restore one’s balance from any position or during any motor activity (Parreira et al, 2017).

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# Chapter 1 Introduction

## 1.1 Introduction

Cricket is a team sport in which two teams of 11 players compete against each other. Each side is comprised of batsmen, bowlers, fielders and wicket keepers (Pardiwala, Rao & Varshney, 2017). In successive innings, one team bowls while the other team bats and attempts to score runs. Usually the team with the most runs wins (Dennis, Farhart, Goumas, Orchard, 2003). Cricket was previously regarded as a moderate risk sport for injury, however, since the increasing prominence of T20 games, the intensity of play and workload on cricketers has increased significantly predisposing players to a wide variety of injuries (Orchard, Kountouris & Sims, 2017). Studies across multiple cricket playing countries have all shown an increase in the incidence of cricket related injuries (Frost & Chalmers, 2012; Stretch & Raffan, 2011, Orchard et al, 2017).

During the 2011 Cricket World Cup, 143 injuries were recorded, 120 of which were new injuries sustained during the tournament (Ranson, Hurley, Rugless, Mansingh, Cole, 2013). A study in South Africa on elite international cricket players reported 113 injuries from 36 players across two seasons (Stretch & Raffan, 2011). According to a longitudinal study of elite senior male cricket players in Australia from 2006-2016, the average incidence of injury was 155 per 1000 days of play (Orchard, Kountouris & Sims, 2016b). Research in New Zealand reported that 415 injuries were sustained by 152 elite cricket players over six seasons, resulting in 2651 days on which players were not available for selection. Of the injuries recorded, 47.3% occurred in the lower limb (Frost & Chalmers, 2012).

There are many factors that predispose an athlete to lower limb injuries (Kiesel, Plisky & Voight, 2007). One of these factors appears to be dynamic postural control (Plisky, Gorman, Butler, Kiesel, 2009). Improved control of neuromuscular proprioception which is brought about by neuromuscular proprioceptive training, has a positive effect on lower extremity biomechanics and has been advocated to prevent primary and secondary lower extremity injury (Filipa, Byrnes, Paterno, Myer, Hewett, 2010).

Dynamic postural control involves maintaining a stable base of support while performing some level of movement (Gribble, Hertel & Plisky. 2012, Herrington, Hatcher, Hatcher, McNicholas. 2009). The Star Excursion Balance Test (SEBT) is a functional screening tool developed by Gray (1995). It was originally a rehabilitative tool which has since been the interest of multiple studies, and has been proven to be successful screening tool (Gribble et al, 2012). It is useful in assessing dynamic stability, strength and range of motion as well as monitoring rehabilitation progress (Filipa et al, 2010; Coughlan, Fullam, Delahunt, Gissane, Caulfied. 2012).

The SEBT measures balance in eight directions: anterior, antero-medial, antero-lateral, medial, lateral, posterior, postero-medial and postero-lateral (Coughlan et al, 2012; Gribble et al, 2012). The time consuming protocol of the SEBT as well as the redundancy in measurements of all eight directions are considered as limitations (Munro & Herrington, 2010, Coughlan et al, 2012). Research has established that only three directions were needed to identify functional deficits, namely, anterior, postero-lateral and postero-medial (Coughlan et al, 2012).

The SEBT in the three abovementioned directions identifies athletes at high risk for lower extremity injury by assessing lower extremity dynamic stability in these directions (Filipa et al, 2010). Factors believed to contribute to neuromuscular stability and thus the ability to maximise the achievable distance in these directions, include available range of motion of the various lower limb joints of the stance and moving leg (Gribble et al, 2012). 3D kinematics supplements simple reach distance outcomes, enhancing the understanding of the lower extremity movement strategies employed during dynamic reach tasks such as the SEBT (Eltoukhy, Kuenze, Oh, Wooten, Signorile 2017; Doherty et al, 2014).

### 1.2 Problem Statement

Although much research has been conducted on the ability of screening tools to predict lower limb injury, there is limited literature regarding the biomechanical analyses of balance tests (Coughlan et al, 2013; Robinson & Gribble, 2008). What remains to be established are the inter- and intra- limb relationships and the kinetics of the balance tests (Robinson & Gribble, 2008). Therefore, the purpose of this study

is to determine whether the SEBT is predictive of injury in cricket players as well as to assess the 3D kinematics of the lower limb during the SEBT.

### 1.3 Research Questions

1.3.1 Is the SEBT predictive of lower limb injury in cricket players?

1.3.2 What are the kinematics, specifically, hip, knee and ankle angles, during the performance of the SEBT?

1.3.3 Is there a link between kinematic hip, knee and ankle angles, and injury?

### 1.4 Aim

1.4.1 To determine if the SEBT and lower limb kinematic hip, knee and ankle angles, are predictive of lower limb injury in cricket players.

1.4.2 To determine the lower limb kinematic hip, knee and ankle angles, of participants during the SEBT.

### 1.5 Objectives

1.5.1 The objectives of this study are to establish the ability of the SEBT score to predict injury in cricket players.

1.5.2 To describe the contribution of lower limb kinematic hip, knee and ankle angles, during execution of the SEBT.

1.5.3 To establish the relationship between the kinematic hip, knee and ankle angles, and injury.

### 1.6 Significance of the Study

There has been a meaningful rise in research into sporting injuries. The first sport to publish recommended methods of injury surveillance was cricket (Orchard et al, 2016). Injuries have since been reported and recorded with increasing frequency (Mansingh et al, 2006). Pre-season and pre-participation screening is commonly

used in sport to identify risk factors for injury in an attempt to research methods of prediction and prevention (Gabbe, Bennell, Wajswelner, Finch, 2004). This study will investigate the SEBT in terms of injury predictive validity. The results from this study will enable clinicians, coaches, etc. to identify at risk individuals and timeously implement injury prevention strategies. The data from the SEBT will be supplemented with kinematic data, which will lead to an improved understanding of the demands that the SEBT places on the body. Additionally, the association of kinematics and injury prevention will serve as preliminary data upon which future research can be built, e.g. the development and testing of injury prevention programmes containing the variables found to be associated with injury and performance.

## Chapter 2: Literature Review

### 2.1 Introduction

Cricket is one of the world's major team sports (Orchard, James, Kountouris, Portus, 2010). It is made up of 11 players each taking on a specific role including batting, bowling, wicket keeping and fielding (Petersen, Pyne, Dawson, Portus, Kellet, 2010; Pardiwala, Rao & Varshney, 2017). Each role has its own demands, and along with that, its own set of associated injuries (Olivier, Stewart, Olorunju, McKinon, 2015; Petersen et al, 2010).

Studies of cricket have shown an increase in the incidence of injuries (Orchard et al 2010; Stretch, 2003). This is due to the increasing demands on players with more matches being played more frequently and with greater intensity (Soomro, Sanders & Soomro, 2015). Injuries have been recorded and reported with increasing frequency in an attempt to research methods of prediction and prevention (Stretch & Raffan, 2011; Orchard et al, 2010; Mansingh et al, 2006).

Reduction in injury means an increased availability of players and improvements in players' performances (Mansingh et al, 2006). In order to successfully prevent injury, ongoing injury surveillance is required (Orchard et al, 2010; Mansingh et al, 2006).

This study used injury surveillance to see if there was a link between objective tests and injury prediction. This chapter will include a review of the literature on injury surveillance, as well some objective tests used to predict injury.

### 2.2 Injury

#### 2.2.1 Definition of Cricket Injury

For injury surveillance to be successful in terms of injury prediction and prevention, as well as its ability to be used as a reference when comparing injury rates in other studies, a concise injury definition is required (Orchard et al, 2005). Sport injury

studies provide definitions for recording cases which in turn provide pragmatic or operational criteria (Fuller et al, 2006, p. 193).

According to several sources and studies across multiple sporting disciplines, injury is defined as ‘that which occurs during matches or practices and causes the athlete to miss at least the next practice session or next game’ (Goldman & Jones, 2011).

The International Football Federation defines an injury more concisely as ‘any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities’ (Fuller et al, 2006, p. 193).

Similarly, the International Rugby Board defines an injury as ‘that which is caused by a transfer of energy that exceeds the body’s ability to maintain its structural and/or functional integrity, sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time loss from rugby activities’ (Fuller et al, 2007, p. 329).

Baseball and softball injuries are defined as ‘any injury that occurs during any baseball or softball sponsored activity, to any muscle, joint, tendon, ligament, bone or nerve or any other body site reported by the player’ (Shanley, Rauh & Michener, 2011, p.649).

Orchard et al, (2005) was the first to publish a recommended method of sports surveillance and this was done in cricket. A method of injury surveillance and a consensus statement was developed by the collaboration of six test-playing nations (Frost & Chalmers, 2012; Orchard et al, 2005). A cricket injury was defined as ‘any injury that prevents a player from being fully available for selection in a match or during a match, and which causes a player to be unable to bat, bowl or wicket keep, whether required by either the rules or team captain ‘(Orchard et al, 2005, p.20).

There was, however, no universal uptake of this definition due to the exclusion of non-time loss injuries (Orchard et al, 2016a). This definition was revised in 2016 and was inclusive of both illness, (‘injury’ refers to injury and illness), and general time loss, meaning a player is unavailable for match play irrespective of whether a match

or training was scheduled (Orchard et al, 2016a). In addition to these, three other definitions were added: medical attention injuries, player reported injuries, and imaging abnormality injuries (Orchard et al, 2016a).

Orchard et al, (2016a) also suggested the mechanism of injury be described to assist in the accurate classification of an injury. An injury can either be classified as a contact injury or non-contact (Fuller et al, 2007). A contact injury results from trauma/impact, whereas a non-contact injury can occur suddenly or gradually in the absence of impact (Orchard et al, 2016a). Stretch and Raffan, (2011) clarify injury classification further by including acute and chronic injury definitions. An acute injury is defined as an injury of rapid onset and a chronic injury involved a prolonged or extended onset (Stretch & Raffan, 2011).

For the purpose of this study, the following definition was used: An injury was defined as, 'any musculoskeletal condition that occurred during practice or a match, which caused the player to either quit that activity or miss at least the next game or practice session'. This definition includes all significant injuries relevant to the musculoskeletal system and excludes any illnesses..

### 2.2.2 Injury Prevalence and Incidence

Through the fundamental process of injury surveillance, there is data of elite cricket players from Australia, New Zealand, England, West Indies and South Africa, as well as data collected from the ICC Cricket World Cup 2011. Studies using the recognised surveillance method showed the incidence of injuries has remained more or less the same but the prevalence of injuries has been steadily increasing (Orchard et al, 2016). Incidence of injury refers to the number of injuries occurring over a period of time, usually seasonal (Stretch & Raffan, 2011; Orchard et al, 2010).The prevalence of injury refers to the percentage of players who are not available for match selection (Orchard et al, 2016).

During the ICC Cricket World Cup 2011, the tournament injury prevalence was 5.1% of players being unavailable on any given tournament day, and match injury prevalence was 4.8% (Ranson et al, 2013). Data was collected from South Africa, Sri Lanka, Pakistan, Zimbabwe and Bangladesh (Ranson et al, 2013).

A separate study of elite male senior cricket players in Australia, over an 11-year period from 1998/1999-2008/2009, prior to the world cup, revealed an average incidence of injury of 35.3 per 1000 match days played (Orchard et al, 2010). The injury prevalence in Australian cricket has increased from 7.2% in 1999 to 10.3% in 2006 (Orchard et al, 2010). Since 2006-2016 it has increased further to 12.2% (Orchard et al, 2016).

In New Zealand, the overall match injury incidence for elite cricket players is 51.6 and the injury prevalence rate was 10.2% over six cricket seasons during the period from 2002-2008 (Frost & Chalmers, 2012). In the West Indies, the mean match injury incidence of elite cricket players, under the West Indies Cricket Board, is 40.6 and prevalence is 9.7% (Mansigh et al, 2006). In elite South Africa, the injury incidence is much higher, for elite international cricket players, at 90 (Stretch & Raffan, 2011). In most research, the incidences of injury at away matches were higher when compared to home games except for Australia (Mansingh et al, 2006; Stretch & Raffan, 2011). A study revealed playing in Australia showed a higher risk of lower limb injury, than when playing at other venues overseas (Orchard et al, 2017). This may be due to the Australian cricket fields, which are also used as Australian football fields, being larger compared to other countries, thus allowing players to reach faster running speeds and exposing them to injury (Orchard et al, 2017; Duhig et al, 2016).

In research conducted in South Africa and New Zealand, overall injuries at practice accounted for 20%-36.7% of all injuries (Frost & Chalmers, 2012; Stretch & Raffan, 2011). In South Africa, 49%-63% occurred during matches (Stretch & Raffan, 2011).

### 2.2.3 Game Types and Injury

There has been an increase in incidence of muscle strain injuries, particularly hamstring injuries, since the T20 format of cricket has increased in prominence and frequency (Orchard et al, 2015). T20 cricket limits a team's scoring to 20 overs i.e. 120 balls for each team (Orchard et al, 2017). Other forms of cricket include one day matches, which limit a team's scoring to 50 overs i.e. 300 balls, and multi-day games, where the scoring is unlimited and dependent upon getting all 10 batsmen from the opposing team out (Orchard et al, 2017). This takes place at a domestic and international level, and generally only one format is played at a time, since

cricketers typically play in all three formats (Orchard et al, 2017). This means more than one form of a cricket match will be played in a season (Orchard et al, 2017).

Research has shown T20 cricket leads to more hamstring injuries, when player hours is the unit of injury incidence, compared to other formats due to the intensity of this form of cricket (Orchard et al, 2017). However, one day cricket was the riskiest format due to the combination of intensity and duration. (Orchard et al, 2017). In South Africa, however, multi day test cricket was found to have greater injury prevalence than One Day International cricket. This is possibly due to this study being the only study conducted in a country over two seasons (Stretch & Raffan, 2011). Petersen et al, (2010) reported multi day cricket, particularly matches three days and longer, to have a greater overall physical load.

### 2.2.4 Injury and Playing Position

#### 2.2.4.1 Bowlers

Players in cricket who bowl the ball with a straight arm, which generally bounces on a pitch before it reaches the batsman, are referred to as bowlers (Orchard et al, 2010). There are typically two types of bowlers, fast and spin bowlers.

##### 2.2.4.1.1 Fast Bowlers

Fast bowlers are undoubtedly influential in determining the outcome of a match and are therefore, generally considered to be an important position in a cricket team (Glazier & Wheat, 2014). A batsman's decision making and stroke execution time is reduced with a faster ball release speed thus potentially limiting runs and possibly increasing the chances of being dismissed (Wickington & Linthorne, 2017). Unfortunately, fast bowlers are also reported to have the greatest risk of injury (Glazier & Wheat, 2014; Stretch, 2003). This is due to fast bowling techniques occurring at a very high intensity (Davie, du Randt, Venter, Stretch, 2008). Studies have revealed the fastest bowlers have quicker run ups; throughout the front foot contact phase, maintain a straighter knee and have larger amounts of upper trunk flexion up to ball release, which permits a more efficient transfer of energy to the ball by delaying the onset of arm circumduction and facilitates faster ball release speeds

(Worthington, King & Ranson, 2013; Portus, Mason, Elliott, Pfitzner, Done, 2004). The injury prevalence in Australia was highest in fast bowlers with a mean of 20.6% in the 11 seasons from 2006-2016 (Orchard et al, 2016). Fast bowlers had the highest incidence of hamstring injuries in multi day cricket. Overall, fast bowling is the activity most associated with sustaining a hamstring injury and fast bowlers were two and a half times more likely to sustain a lower limb muscle injury, compared to spin bowlers (Orchard et al, 2017). A study looking at cricketers during a T20 match recorded the distance covered of fast bowlers, by using a GPS system, to be 8.5km during which sprinting accounted for 9% of total distance (Petersen, Pyne, Portus, Dawson, 2009). In the same study, it showed fast bowlers sprinted 32 times more than spin bowlers (Petersen et al, 2009).

#### 2.2.4.1.2 Spin Bowlers

A study from 2009 reported that, even though most of the attention is given to fast bowlers in terms of dismissing batsman, the world's three highest "wicket takers" were spin bowlers (Chin, Elliot, Anderson, Lloyd, Foster, 2009). Spin bowlers have a much shorter run up and in general sustain far fewer injuries than fast bowlers. Data from Australia and New Zealand showed injury prevalence for spin bowlers was 13% less than fast bowlers (Orchard et al, 2016; Frost & Chalmers, 2012). During a GPS study by Petersen et al, (2009) the total distance covered by spin bowlers during a T20 match was shown to be almost the same as fast bowlers. However, sprinting only accounted for 2% of total distance. The injury prevalence for spin bowlers during the ICC Cricket World Cup 2011, and in injury surveillance in New Zealand, accounted for around 5.5% in both studies and 6.7% in Australia (Ranson et al, 2013; Frost and Chalmers, 2012; Orchard et al, 2016).

### 2.2.4.2 Batsmen

During the ICC Cricket World Cup 2011, batsmen sustained the highest injury prevalence at 5.7% (Ranson et al, 2013). A similar prevalence was found in New Zealand at 5.4% and a much higher prevalence of injury was recorded in Australia at 7.4% (Frost & Chalmers, 2012; Orchard et al, 2016). In a South African study, batting accounted for 23% of injuries across two seasons (Stretch & Raffan, 2011). Batting and fielding had the highest incidence of injury in T20 cricket and in one day

matches (Orchard et al, 2017). This correlates with the research that showed that, compared to longer formats of cricket, a greater proportion of time batting in T20 cricket is spent at higher intensities (Petersen et al, 2009). The overall relatively low prevalence may be attributed to the significantly less distance covered per match by batsmen when compared to other roles, at just 2.5km, of which 7% of this was sprinting, batsmen make up only 7% of the total distance covered by all roles, (Petersen et al, 2009).

#### 2.2.4.3 Fielders

Fielding has become more athletic through the development of one day games in cricket (Von Hagen, Roach, Summers, 2000). Fielding skills such as speed and accuracy are common requirements particularly in the one day and T20 games (MacDonald, Cronin, Mills, McGuine, Stretch, 2013a). Fielders covered a distance of 8.1km during a T20 cricket match, the second highest number of high intensity efforts, with a total of 31 sprints in a match (Petersen et al, 2009). Sprints by the combination of fast bowlers and fielders during this study made up 72%, putting the two at the highest risk of muscle injuries. In a study from New Zealand, fielding accounted for 14% of injuries. In South African, 24% of injuries were acquired when fielding, and in Australia, 108 major match injuries were sustained over an 11-year study (Frost & Chalmers, 2012; Stretch & Raffan 2011; Orchard et al, 2005). The incidence of hamstring injuries was 13.4, 8.6 and 4.1 per 1000 team days for fielders for One Day International, first class matches and T20 cricket respectively (Orchard et al, 2017).

#### 2.2.4.4 Wicket Keepers

Wicket keepers' role is to intercept fast-moving balls coming off the edge of the bat and reaching them below chest height (MacDonald, Cronin, Mills, Stretch, 2013b). A wicket keeper generally keeps wickets in at least 50% of matches (Frost & Chalmers, 2012). In Australia, the mean prevalence of injury was 4.8% from 2006-2016 (Orchard et al, 2016). Wicket keepers, during a T20 match covered a distance of 6.4 km's, however, only 1% was attributed to sprinting (Petersen et al, 2009). Across all literature reviewed, wicket keepers sustained the least number of injuries (Orchard et al, 2016; Frost & Chalmers, 2012).

### 2.2.5 Lower Back and Lower Limb Injuries

The average seasonal incidence for lower limb injuries in Australia, over the 11-year period from 1998-2009, was 9.8 and from 2006-2016 averaged 8.7, which made up 56% of total body injuries compared to the upper quarter (upper limb, head and neck), which made up only 34% (Orchard et al, 2016b, Orchard et al, 2010). In South Africa, lower limb injuries made up 49.8% (Stretch, 2003). Similarly, in New Zealand, the lower limb region was the most frequently injured body region, compared to other sites, and made up 47.3% (Frost & Chalmers, 2012). The hamstring muscle was the most common injury with the sustained in South Africa, New Zealand and Australian cricket (Orchard et al, 2016; Stretch, 2003). The thigh and hamstring was also found to have the highest incidence of time loss injuries from a study conducted during the 2011 Cricket World Cup (Ranson et al, 2013). Lumbar stress fractures were the most prevalent injury and resulted in a significant number of missed match days according to most literature (Orchard et al, 2016; Frost & Chalmers, 2012).

### 2.2.6 Types of Injuries

Muscle tears/sprains were the most common injury found in cricket players across a number of studies conducted in multiple countries (Frost & Chalmers, 2012; Stretch & Raffan 2011; Mansingh et al, 2006). Research using GPS in cricket showed the incidence of hamstring injuries strongly correlated to the number of sprinting efforts measured (Petersen et al, 2010). Other research has shown posterior thigh pain and hamstring muscle injuries, in particular, have a high re-injury rate, with 3.7 times higher risk if the previous injury occurred in that season, and 2.7 times higher if the injury occurred in the previous season. It also showed that recurrent injuries result in significantly more lost time and are generally more severe (Lui, Garrett, Moorman, Yu, 2012; Orchard et al, 2017). The literature suggests previous injury is a very strong predictor of current injury in fast bowlers (Stretch & Raffan, 2011). This may be due to disturbed proprioception as a result of pain, effusion and trauma (Clark, Roijezon & Treleaven, 2015). Previously injured muscles also show a decreased ability to work through full range of motion, increasing the risk of future, and re-injury (Lee, Reind, Elliot, Loyd, 2009).

Lumbar spine injuries are the most prevalent injury in cricket as they caused the most amount of missed time (Orchard et al, 2016). They are either sustained acutely during bowling, or can be chronic, due to repetitive stress of combined lumbar extension, contralateral side flexion, and ipsilateral rotation sustained during bowling (Pardiwala et al, 2017; Portus et al, 2004). This puts fast bowlers at a particularly high risk.

### 2.2.7 New Versus Recurrent Injuries

New injuries can either occur suddenly (acute) or have a gradual onset and can either be due to contact or non-contact. The majority of cricket injuries are non-contact (Orchard et al 2016b). Once an injury has resolved it can reoccur. According to Orchard et al, (2016) a recurrent injury, in general terms, is one of the same type, which reoccurs in the same season (surveillance year) after it has been defined as recovered. Data from South Africa showed the mean new injuries in the study over two seasons to be 76% and recurrent injuries to be 14%. Acute injuries accounted for 87%, chronic injuries 2%, and gradual onset injuries 19% (Stretch & Raffan, 2011). This study also reported on acute-on-chronic injuries, which accounted for 11% (Stretch & Raffan, 2011). In New Zealand, 1.7% of injuries were categorised as gradual onset injuries (Frost & Chalmers, 2012). The West Indies cricket study reported 80% of injuries were new, 76% acute, 16% acute-on-chronic, 8% chronic and only 10 % were recurrent (Mansingh et al, 2006). In Australia, the mean annual injury incidence for new injuries per 100 players per year was 64% (Orchard et al. 2016).

The highest recurring injury in sport, in general, according Erickson and Sherry (2017) are hamstring related injuries. This may be due to inadequate return to sport criteria (Sherry, Johnston & Heiderscheit, 2015). Returning to sport prematurely and not allowing tissue healing may result in persistent muscle weakness in the injured muscle and reducing the flexibility of the musculotendinous unit as a result of scar tissue formation (Orchard &Thomas, 2002).

### 2.2.8 Recovery Time

According to Orchard et al, (2016, p. 1247), ‘general recovery is when medical staff have determined that the player has returned to match availability, regardless of whether a match is scheduled for that day or not’. A study that included recovery time from injury showed 26% of injured players were able to return to practice or matches within 7 days, 11.5% returned within 8-21 days and 26.1% could only return after more than 21 days (Stretch & Raffan, 2011).

Table 2. 1 Summary of injury epidemiology

| Country | Incidence of injuries | Prevalence of injuries | Game Type | Injury prevalence by position | Most frequent Injury Type | Most prevalent | New or Recurrent |
|---|---|---|---|---|---|---|---|
| South Africa (Stretch and Raffan 2011) | 90 | 3.8 | 79 One day<br>95 Tests | Bowling (27%)*<br>Batting (23%)*<br>Fielding (24%)* | Lower limb | Lumbar injuries | New 76%<br>Recurrent 14% |
| Australia (Orchard et al 2016) | 155<br>*per 1000 days of play | 12.5 | 283 One Day<br>118 Tests | 20.6% Fast bowler<br>6.7% Spin bowlers<br>7.4% Batsmen<br>4.7% Wicket keeper | Hamstring/lower limb muscle | Lumbar injuries | New 64% |
| West Indies (Mansingh et al 2006) | 51.6 | 9.7 | 40.6 One day<br>48.7 Tests | Fast bowlers 40%)*<br>Batsmen (40%)*<br>Spin Bowler (4%)*<br>Wicket keeper (4%)* | Muscle Strains | Lumbar injuries | new 80%<br>Recurrent 10% |

| Country | Incidence of injuries | Prevalence of injuries | Game Type | Injury prevalence by position | Most frequent Injury Type | Most prevalent | New or Recurrent |
|---|---|---|---|---|---|---|---|
| New Zealand (Frost and Chalmers 2012) | 51.6 | 10.2 | 73.1 One day<br>30.1 Tests | 18.7% Fast bowlers<br>5.5% Spin bowlers<br>5.4% Batsmen<br>3.8% Wicket keeper | Lower Limb muscle sprains | Lumbar injuries | No Data |
| ICC Cricket World Cup 2011 (Ranson, et al 2013) | 314.3 | 5.1 | N/A | 4.6 Fast bowlers<br>5.4 Slow bowlers<br>5.6 Batsmen<br>0 Wicket keeper | Thigh muscle strain | Ankle | |

*percentage of injury per activity

## 2.3 Biomechanics

Biomechanics is the study of mechanical laws and their application to living organisms, particularly the human body and its movement (Richards, 2008). There have been multiple studies that have assessed the biomechanics of cricket players in the various playing positions (Olivier et al, 2016; Glazier & Wheat 2014; Chin et al, 2009).

### 2.3.1 Biomechanics of fast bowling

Of the numerous biomechanical studies conducted, a large portion was done on the bowling action of cricket players. In particular, fast bowlers, due to their bowling action, and its high risk of lower back and lower limb injury (Glazier & Wheat, 2014; Olivier et al, 2016). Other studies looked at factors of bowling that increase the risk of injury (Glazier & Wheat, 2014). The bowling biomechanics are broken down in literature as follows: the run up, pre-delivery stride, delivery stride, and follow through (Glazier & Wheat, 2014).

The run up is defined as the phase between the start of the bowler's approach run to the moment of take-off for the pre-delivery stride (Glazier & Wheat, 2014). The pre-delivery stride occurs between the end of the run up and before the back foot makes impact at the start of the delivery stride. The run up and pre-delivery stride combined are typically 15–30m in length and the run up speeds range from 4.8-6.8m.s (Worthington et al, 2013).

The delivery stride has been defined as the moments between back foot impact and ball release (Glazier & Wheat, 2014). Front foot impact occurs at 70% of this phase and has received a lot of attention in literature, as most studies appear to support the view that bowling with a straight, or even hyperextended, front leg at ball release can lead to greater ball release speeds. But this has also been associated with an increased risk of injury (Worthington et al, 2013; Glazier & Wheat, 2014).

Lastly, follow through is generally defined as 'the period from ball release to one to three strides post-release' (Glazier & Wheat, 2014. p. 30.) The follow through has no

bearing on ball release speed, but is important for injury analysis and prevention, as decelerating too abruptly can result in muscle strains (Glazier & Wheat, 2014).

### 2.3.2 Biomechanics of spin bowling

Biomechanics of spin bowlers are for the most part similar to fast bowlers. The differences are seen during the delivery stride, as the front foot lands pointing in the direction of the batsman and there is a comparatively shorter stride length than fast bowlers (Chin et al, 2009). This study also spoke in depth of several differences in the upper limb biomechanics when releasing the ball in order to create the spin (Chin et al, 2009).

### 2.3.3 Biomechanics of batting

Fewer studies looked at batting biomechanics. Batting is on the receiving end and is a dynamic interceptive action, largely determined by the execution of an appropriate motor response, which is determined by a player's successful ability to use delivery information (Penn & Spratford, 2012). As cited in Penn and Spratford (2012), batting consists of the stance and initial movement; followed by back-lift and forward stride; downswing; then bat-ball impact; and lastly the follow through (Stuelcken et al. 2005).

During the stance phase the goal is for the batsman to be in a comfortable, relaxed and well-balanced position, enabling the batsman to play forwards or backwards, or to attack or defend (Woolmer, Noaks & Moffet, 2008). To ensure that the batsman is well balanced at the crease, the head and body's centre of mass must be either aligned, or slightly forward of the body's base of support, and the alignment of the shoulders, hips and knees should be parallel to the crease (Woolmer et al, 2008).

Back-lift biomechanics in the literature, suggest that the orientation of the bat is in the transverse plane, provided the batsman and bat are in the correct position at impact (Woolmer et al, 2008). This is also found in the literature reviewing the forward stride, where the suggestion is that the batsman simply takes a comfortable stride forward. No reference is made to an appropriate time of initiation or stride length (Penn & Spratford, 2012).

Downswing biomechanical studies suggest that for optimal stroke production, the upper limbs of both the top and bottom hands should work together in a pendula movement through the downswing, and there should be more extension of the front knee and a vertical thigh alignment at impact (Woolmer et al, 2008).

Again, there is not much literature on the biomechanics of the follow through, except that this phase is largely diagnostic of successful shot execution and maintenance of balance through the shot (Woolmer et al, 2008).

### 2.3.4 Biomechanics of wicket keeping

Very limited studies have considered the biomechanics of wicket keepers. Wicket keeping biomechanics are based on energy conservation as this role is unique in that the wicket keeper is the only player who has the potential to be involved in every delivery of the innings (McDonald et al, 2013). The biomechanics are generally broken up into three phases: crouch, semi crouch and touch and move stance (McDonald et al, 2013). The full crouch position is generally a resting position where the knees are static in a fully flexed position. This position is generally used by most wicket keepers, however; it does cause high compression forces on the knee and requires a greater range of lower limb extension in order to catch the ball during the move stance (McDonald et al, 2013).

The next two phases are also known as the power or loading phase. The semi crouch and touch should not be held for more than 2 seconds to ensure that the power in the muscles is not lost prior to movement (McDonald et al, 2013).

During the movement phase, wicket keepers perform lateral steps to catch the ball (McDonald et al, 2013). A study by Rosen and Bower, (2006) showed the average primary step length was between 54.5 ± 27.5 cm.

### 2.3.5 Biomechanics of sprinting

All cricketers must field and complete maximal sprints despite the position they play (Robert, Callaghan & Jeffriess, 2014). Sprints during cricket are often centred on crucial match situations such as the run up and delivery during fast bowling, sprinting to field the ball or running between wickets (Petersen et al., 2010; Rudkin &

O'Donoghue, 2008). Fielding in cricket will often require maximal sprints, usually over short distances, in pursuit of the ball after it has been hit by a batsman (Rudkin & O'Donoghue, 2008). Studies using GPS in cricket showed fast bowlers sprint more often than other roles. Batsmen sprint more in T20 and one day matches than in multi day cricket and fielders have the highest amount of sprint efforts in the latter. (Petersen, Pyne, Dawson, Kellett, Portus, 2011; Petersen et al, 2010). This correlates with the higher rate of hamstring injuries in fielding seen in multi-day matches (Petersen et al, 2011).

The study showed during sprinting there was a longer second step and greater flexion angles of the hip and knee. Greater plantarflexion contributed to increased step length in cricketers. These lower limb kinematic angles, influence increasing step lengths which in turn impacts sprint acceleration and longer strides therefore, enhances speed over short distances (Robert et al, 2014).

### 2.3.6 Biomechanics and injury

During the ICC Cricket World Cup 2011, the activity that resulted in the highest incidence and prevalence of injury was the delivery stride and follow through phase of bowling, followed by running during fielding and batting (Ranson et al, 2013).

Although this review focuses on the lower limb, most of the biomechanical research on cricket players and injury has focused on lumbar variables. These kinematic studies have shown ground reaction forces were the largest in both vertical and horizontal planes during the power phase (Ferdinands, Kersting & Marshall, 2009). During this phase the angular velocity of lumbar spinal segments are high in all planes of motion, i.e. flexion, lateral flexion and rotation. Together with the powerful muscle action that controls the motion at this segment, the lumbar spine is subjected to high dynamic loads and therefore, the risk of injury in the lumbar spine in increased (Ferdinands, Kersting & Marshall, 2009; Ranson et al, 2008).

Crewe et al, (2013) found an association in adolescents between lumbo-pelvic shear forces and more extended front knee during the front foot contact phase. Bowlers that had greater knee flexion at front foot impact and during ball release where

characteristics of cricket players who did not sustain an injury in two studies (Olivier et al, 2015; Portus et al, 2004).

Biomechanical research on the lower limb suggests muscle strain injuries often occur during eccentric contraction (Lee et al, 2009). Research suggests muscle strain injuries often occur during eccentric contraction (Lee et al, 2009). In particular the risk of sustaining a hamstring injury has two major components. The first component is stretching and lengthening of the hamstring muscles and the second is eccentric contraction of the hamstring (Schache, Wrigley, Baker, Pandy. 2009).

Sufficient range of motion is required to allow the muscles to stretch and lengthen during sprinting, either between the wickets or on the field (Potier, Alexander & Seynnes, 2009). Studies have shown a decrease in range of movement increases the risk of injury (Henderson, Barnes & Portas 2009). A study conducted on elite soccer players showed that players with decreased hip and knee flexion range of motion incurred muscle strains more frequently (Bradley & Portas, 2007).

Other biomechanical studies showed the joints in the lower extremity function are inter-related in the sagittal plane (Fong, Blackburn, Norcross, McGrath, Padua, 2011). Joint motions of the lower limb during closed chain activities are interdependent and excessive movements in one joint may overload tissues in other areas of the kinematic chain (Barwick, 2012). Dennis et al, (2008) study showed increased hip internal rotation was associated with a higher risk of injury in cricket players. Excessive frontal and transverse plane motion during functional activities, may indicate a risk of musculoskeletal injury in specific sporting activities such as running (Chuter, Janse & de Jonge, 2012).

The second component, eccentric muscle contraction, is a risk factor when it rapidly decelerates hip flexion and controls knee extension (Schache et al, 2009; Lee et al, 2009). This is evident in research from the West Indies, as many of the muscle strain injuries were caused by running after picking up the ball and in South Africa, where injuries were sustained when diving to stop the ball, regaining balance and then attempting a quick return to secure a run out. Both require eccentric muscle control (Stretch & Raffan, 2011 Stretch 2003; Mansingh et al, 2006). Eccentric muscle control relies on postural control particularly, proprioception (Clark et al, 2015).

## 2.4 Neuromuscular-skeletal risk factors

Due to the biomechanical nature of the sport, identifying the neuromuscular- skeletal risk factors for injury in cricket players is of particular concern as the prevalence of injury is rising (Orchard et al, 2016). Some of these identified risk factors may be modifiable and easily identified through pre-participatory screening tools and addressed through injury prevention programmes (Olivier et al, 2016).

In terms of range of movement, as discussed, Dennis et al, (2008) identified an increase in hip internal rotation of >40° on the back foot and a reduced ankle dorsi-flexion range of <14cm, to be associated with an increased risk of injury.

Muscle control and imbalance was investigated by Hides et al, (2007) who found cricket players with lower back pain displayed a reduced ability to contract the transverse abdominis muscle in isolation from the other abdominal muscles. Furthermore, the author revealed cricket players with lower back pain had a greater quadratus lumborum muscle asymmetry on MRI than those who were pain free (Hides et al, 2007). Kountouris et al, (2013) and Engstrom et al, (2007) both investigated the relationship between quadratus lumborum asymmetry and lumbar spine injuries in adolescents, but published conflicting results. Engstrom et al, (2007) found a strong association between quadratus lumborum asymmetry and L4 pars lesions whereas Kountouris et al, (2013) found no relationship between these variables.

With regards to joint position sense and proprioception, Olivier et al, (2014) reported previous injuries, and injuries sustained during the cricket season under review, were both associated with a reduced joint position sense. Proprioception, in terms of balance, was also investigated by the same author, who found pace bowlers that were injured, had lower dynamic balance scores, compared to their healthy counterparts (Olivier et al, 2015).

Most of the research reviewed for neuromuscular skeletal injuries, was focused on lumbar variables. However, poor proprioception and balance have been associated with both spinal and peripheral injuries (Olivier et al, 2016). Proprioception is a

modifiable risk factor and is a requirement for optimal postural control and balance (Olivier et al, 2016).

### 2.5 Postural control and balance

Postural control is the inherent ability to establish and restore one's balance from any position or during any motor activity (Parreira et al, 2017). Postural control or balance can be grouped into two categories, static and dynamic. Static postural control tasks require a stable base of support and maintenance of this position while minimising segment and body movement (Gribble et al, 2012). Dynamic postural control and balance, involve the level of expected movement and the ability to perform a task while maintaining a static, stable base of support (Gribble et al, 2012; Winter et al, 1990). With regards to static balance, the organisation of sensory information may be most important, whereas in dynamic balance, lower limb flexibility, strength and coordination may be more important (Plisky et al, 2006; Gribble et al, 2012). Proprioception is essential for well adapted sensorimotor control (Clark et al, 2015). Proprioception fulfils the roles in feedback and feedforward sensorimotor control and regulation of muscle stiffness is specifically important for joint stability, co-ordination, movement acuity and balance (Clark et al, 2015).

In sports, it is important to be able to maintain balance and functional joint stability during dynamic tasks in order to mitigate the risk of injury (Eltouzkhy et al, 2017). Proprioceptive deficiency facilitates injury and causes abnormal stress accumulation in the surrounding tissues contributing to further joint problems (Zazulak et al, 2007). Training directed towards improving proprioception has been associated with a decrease in injury risk, therefore, targeting proprioception has been relevant in both prevention and rehabilitation of musculoskeletal disorders (Roijezon, Clark & Treleaven 2015).

Thus, measures of static and dynamic balance can be used as tools to assess lower extremity injury risk (Gribble et al, 2012; Dallinga, Benjaminse & Lemmink, 2012). However, the underlying tasks of standing still during static balance tests may not be translated to movement during physical activity (Gribble et al, 2012). Dynamic balance tests are therefore preferable as they mimic the demands of physical activity by dictating complex movement around a base of support (Gribble et al, 2012).

### 2.5.1 Balance and Injury

Balance deficits are a measure of neuromuscular control. Dynamic balance tests are more appropriate in sports as they are highly challenging and capable of detecting stability problems (McKoen & Hertel, 2008; Wikstrom et al, 2010). Many studies have proven a link between specific injuries and a lack of postural control such as patellofemoral pain syndrome (PFPS), muscle strains and ligament tears.

Patients with PFPS demonstrated a deficiency in postural control (Aminaka & Gribble, 2008). A study looking at active joint position sense in patients with PFPS found significantly increased reproduction errors when instructed to reproduce specific previously instructed knee angles in supine, compared to the knee without pain and to healthy participants indicating reduced proprioception and balance in the painful knee (Akseki, Akkaya, Erduran, Pinar, 2008).

Similarly, Sole et al, (2012) found there was an early onset of activation of the hamstring muscles during a balance test in the participants with previous hamstring injury, suggesting there is altered neuromuscular control and proprioception following muscle strains.

This can be seen in studies that have shown that postural control and particularly dynamic stability, also play a role in anterior cruciate ligament (ACL) injury prevention (Smith & Bell, 2013). The research also showed that rupture of ligaments impairs motor control and co-ordination of muscles surrounding the knee, by disrupting neural feedback loops related to joint position sense and movement (Smith & Bell, 2013). Another study showed the Balance Error Scoring System was much higher in participants with ACL repairs when compared to their healthy counterparts. This was also found in patients with functional ankle instability in another study (Smith & Bell, 2013).

It has been reported that lateral ankle instability is often associated with poor postural control, which was found to be impaired after acute ankle sprains, in both males and females of various sporting codes, with deficits in both the injured and non-injured limb compared to the control group (McKoen & Hertel, 2008). A number of other studies showed patients with chronic ankle instability suffer from disrupted

neuromuscular control which has been shown to predict future sprains (Gribble et al, 2007; Willems et al, 2002; Olmstead et al, 2002).

Multiple other studies have demonstrated athletes, participating in neuromuscular training programs, have shown decreased injury rates for anterior cruciate ligaments, combined lower extremity injuries, sprains and ankle sprains (McLoed, Armstrong, Iller, Sauers, 2009).

Therefore, it is important to establish assessment techniques that can provide reliable, sensitive, and cost effective information about dynamic movement. One such test is the SEBT (Pilsky et al 2009). The SEBT is a dynamic test that requires strength, flexibility, and proprioception (Pilsky 2009).

## 2.6 Star Excursion Balance Test

The SEBT was originally described as a rehabilitative tool by Gray, G in (1995) (Gribble et al, 2012). The SEBT is a series of single-limb squats using the non-stance limb to reach as far as possible along one of eight designated lines on the ground arranged in orientation to the stance limb (Gribble et al, 2012). The goal of the task is to have the individual establish and maintain a stable base of support on the stance limb with the mid-foot at the apex of the testing grid, while attempting to execute a maximal reach excursion in one of the prescribed directions (Gribble & Hertel, 2003). It measures dynamic balance in eight directions: anterior, antero-medial, antero-lateral, medial, lateral, posterior, postero-medial and postero-lateral (Coughlan et al, 2012; Gribble et al. 2012). Each direction requires a combination of sagittal, transverse and frontal plane movements, and offers different challenges while maintaining a stable base of support during movement (Gribble et al, 2012). According to a systematic review by Gribble et al, (2012) the SEBT can provide objective measures to differentiate both deficits and improvements in dynamic postural control and potentially predict lower extremity injury. Limitations associated with the SEBT are its time-consuming protocol of nine trials as well as the redundancy in measurements of all eight directions (Munro & Herrington, 2010; Coughlan et al, 2012; Robinson & Gribble, 2008). Research established that only three directions were needed to identify functional deficits, namely; anterior, postero-lateral and postero-medial (Coughlan et al, 2012).

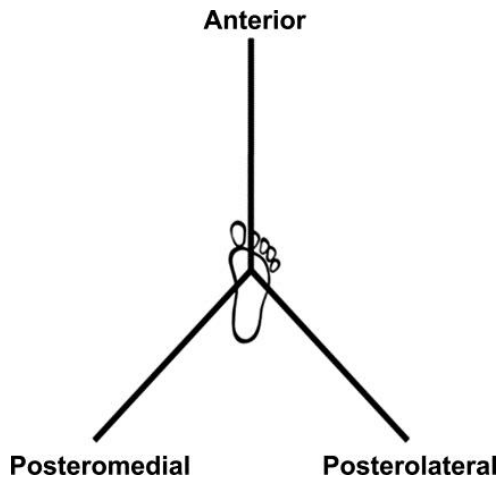



Figure 2. 1: SEBT diagram (Clark et al, 2010)

### 2.6.1 Star Excursion Balance Test and injury

The SEBT identifies athletes at high risk of lower extremity injury by assessing lower extremity dynamic stability in the abovementioned three directions (Filipa et al, 2010). The reach distance values are used as an index for dynamic postural control (Gribble et al, 2012). According to Robinson & Gribble, (2008) only four trials need to be performed as familiarisation before measuring reach distances. The validity of the study is still maintained and the learning effect is decreased without hindering the participants' ability to perform the test. Similarly Munro and Herrington, (2010) found that the SEBT stabilised after four trials.

In order for valid comparison to be made, Gribble et al, (2012) discussed that the normalisation of reaching distance to the participants' leg length was necessary. This allows performance to be recorded as a percentage of leg length and therefore, accounts for leg length differences in individuals by using the maximised reach distance formula (distance/limb length) x 100 (Coughlan et al, 2012).

Multiple studies have reported consistently strong inter-rater and intra-rater reliability. Most recently Clark et al, (2010) reported an excellent test-retest reliability and inter-rater reliability scores of ICC = 0.98 and 0.91, respectively. The predictive validity of the test to determine injury was also explored by a number of researchers (Gribble et al, 2012). Plisky et al, (2006) reported that the sum of three reach directions (anterior, postero-medial, and postero-lateral), as well as between limb asymmetry in the anterior reach distance, was predictive of lower extremity injury in high school basketball players. The same study also found players with a reach difference of four cm or more, doubled their likelihood of sustaining a lower limb injury. Females with a composite reach score of less than 94%, were six and a half times more likely to sustain a lower extremity injury (Gribble et al, 2012).

Hubbard et al, (2007) reported persons with chronic ankle instability could be identified by the scores in the anterior and postero-medial reach directions. In a second study, hip abduction strength was found to correlate with the postero-medial reach distance, and hip extension strength with postero-lateral reach distance on the SEBT. Herrington et al, (2009) found that participants with ACL deficient knees displayed decreased reach distances in the anterior and postero-medial direction, when compared to both, their non-injured limb and to the control group. Olmstead et al, (2002) demonstrated in a population with chronic ankle instability, the reach distance was significantly less when standing on the injured limb (78.6cm) compared to their non-injured limb (81.2cm). A study assessing dynamic balance by means of the SEBT on cricket players, found bowlers who had sustained an injury in the cricket season under review, had decreased reach distance in the postero-medial direction while standing on the right leg, when compared to the group with no lower quarter injuries (Olivier et al, 2015). The SEBT has also been reported to identify bowlers who are at high risk of lumbar injuries; poor performance is predictive of injuries later in the season (Pardiwala et al, 2017; Olivier et al, 2015).

However, studies looking at biomechanical analyses of balance tests have been limited (Robinson & Gribble, 2008). Some of what remains to be known are the inter- and intra-limb relationships and the kinetics of the balance tests (Robinson & Gribble, 2008). This study will attempt to fill in this void by analysing the SEBT and 3D kinematics and kinetics.

### 2.6.2 Three-dimensional kinematics of the Star Excursion Balance Test

Kinematics is the study of motion of the body without regards to the force acting to produce the motion (Richards, 2008). Reflective markers are stuck on the skin of participants in correspondence with targeted anatomical landmarks, axes or planes (Leardini et al, 2007). This allows for three dimensional (3D) body segment position and the orientation to be calculated, as well as relative motions and joint positions through the trajectories of these markers obtained during the execution of the motor task under analysis, providing that they are visible to at least two high speed cameras (Leardini et al, 2007). 3D kinematics has been shown to be reliable in a number of studies, particularly with regards to the sagittal and coronal plane during gait analysis (Pohl, Lloyd & Ferber, 2010). Another study that reviewed the active motion analysis of typists found 3D kinematics to be both valid and reliable (Levanon, Gefen, Lerman, Givon, Ratzon, 2010). However, this involves careful placement of the retro-reflective markers (Macaulay, Osis, Clermont, Ferber, 2017).

Joint kinematics, influenced by muscle strength, proprioceptive function or neuromuscular control, has been documented as crucial factors for performance on dynamic post control tests (Robinson & Gribble, 2008). It enables clinicians to assess dynamic balance performance more objectively (Eltoukhy et al, 2017).

3D kinematics supplement simple reach distance outcomes and provide a more comprehensive understanding of the lower extremity movement strategies employed during dynamic postural tasks such as the SEBT (Eltoukhy et al, 2017; Doherty et al, 2014). Studies show it not only allows investigation of the task outcome, but also provides information regarding potential kinematic source of the poor performance (Eltoukhy et al, 2017).

There are many factors believed to affect one's ability to achieve maximum reaching distance (Gribble et al, 2012). Multiple studies, such as those performed by Gribble, et al, (2007) and Olmsted et al, (2004) suggest that hip and knee movements in specific planes influence SEBT performance. Hoch et al, (2011) strongly correlated ankle dorsiflexion range of motion with anterior reach distance in healthy individuals. This suggests lower extremity sagittal plane kinematics appear to be the greatest contributor to SEBT performance in healthy individuals (Hoch et al, 2011).

Studies examining kinematics in injured participants showed the use of different movement strategies, which may be more reliant on transverse and frontal plane of motion to execute movement goals (Hoch et al, 2011; Doherty et al, 2014). These studies showed lower extremity injury may not only affect SEBT performance, but the kinematic strategy utilised to complete the SEBT may be different (Doherty et al, 2014). Therefore, SEBT performance and lower extremity kinematics may be related to the type of injury (Doherty et al, 2014). This highlights potential controlling factors during injury risk evaluation.

## 2.7 Conclusion to the Literature Review

In the past, cricket was considered a low risk sport; however, since the introduction of T20 games and with cricket now being played almost all year round, the workload on players has increased dramatically. As a result, the reported injury incidences and prevalence from most cricket playing countries have also increased substantially. Lower limb and lumbar injuries are of a particular concern. Monitoring the risk factors during congested fixture periods could provide valuable information for early detection and management of potential injury risk (Timpka & Jacobson, 2014). This will allow for more availability of players during matches, a better quality of life for cricket players, and reduced medical costs for teams. Therefore, it is of utmost importance for the entire cricket management and medical team to keep a player injury free for as long as possible, and opportunities should be explored to reduce incidence of injuries (Stretch & Raffan, 2011; Frost & Chalmers 2012). One such cost- effective and efficient assessment tool is the SEBT.

This study has combined the SEBT with 3D kinematics to provide more specific information on, not only which players are at risk, but also the potential kinematics responsible for the increased risk of injury.

# Chapter 3 Methods

## 3.1 Introduction

In this chapter, the study design, participants, outcome measures, ethics, procedure and statistical analysis will be discussed.

## 3.2 Type of Study and Study Setting

This is an observational, longitudinal cohort study. Data collection took place at Wanderers Cricket Stadium, Illovo, Johannesburg.

## 3.3 Participants

### 3.3.1 Source of Participants:

Volunteers were recruited from the Highveld Lions, the Gauteng Strikers and the Gauteng Provincial under-19 team. These teams were exposed to similar pre-season training routines and all the teams partook in training sessions as well as multiple games weekly.

### 3.3.2 Sample Selection

The sample size was calculated using the means from a similar study by Plisky, et al, (2006). The power of the study was set at 90% and the significance at 0.05. The calculation suggested 19 participants. However, taking into account drop-out rates and non-compliance, the study included 22 participants, in order to draw statistical inference to the general population.

#### 3.3.2.1 Inclusion Criteria

Injury free male cricket players participating in the 2015/2016 cricket season were considered for inclusion into this study.

#### 3.3.2.2 Exclusion Criteria

The following exclusion criteria were applied:

- Participants with history of any central nervous system or peripheral nervous system disorders that affect proprioception (Pereira, et al., 2008).
- Participants with fractures that had not been cleared for testing.
- Participants with a history of concussion or vestibular disorders in the previous six months.
- Participants receiving proprioception training.
- Participants who do not consent to the study.

## 3.4 Instrumentation and Outcome Measures

### 3.4.1 The Star Excursion Balance Test

The SEBT is a multi-directional screening tool designed to challenge, among other aspects, postural control and proprioceptive abilities (Filipa et al, 2010; Coughlan et al, 2012). The SEBT was found to be an excellent neuromuscular balance screening tool (Gribble et al, 2012). The test procedure was as follows: The participant stood in shorts with the stance limb on the apex of the measuring tapes with their hands on their hips (Gribble, Kelly, Refshauge, Hiller, 2013). To eliminate stability and balance influence from shoes, participants were barefoot (Coughlan et al, 2012).

The measuring tapes were stuck to the ground in the anterior, postero-medial and postero-lateral directions. The tape measure in the anterior direction was placed 135° apart from the postero-medial and postero-lateral tape measures and the two posterior tape measures were spaced at a 90° angle from one another (Couglan et al, 2012). They were instructed and shown how to reach as far as possible in the anterior then postero-medial and lastly postero-lateral direction. The reach distance was recorded when a light toe touch on the tape measure was performed and the reach limb was able to return to the stance limb while maintaining equilibrium (Gribble et al, 2013). The reach foot was not placed flat on the ground nor did it have sufficient weight passing through the foot as to gain an increase in distance (Coughlan et al, 2012). The stance foot had to remain still, and the heel remained

flat. The participants had to complete four trials before their final distance was recorded (Gribble et al, 2012). This has been shown to decrease the learning effect without hindering their ability to perform the test (Coughlan et al, 2012). The participant's trial was discarded and repeated if the individual's reaching foot was placed flat on the ground or was unable to return to the starting point, as well as if the individual's stance heel lifted or the foot moved (Fullam, Caulfield, Coughlan, Delahunt, 2014). The process was repeated in the postero-lateral then postero-medial directions. Both the dominant and non-dominant limb was tested and therefore, the order of the test leg was randomised at each session. Dominance of the leg was determined by participants and not measured. The direction order went as follows: anterior, postero-medial then postero-lateral in order to avoid confusion during kinematic analysis. A two minute rest period was given between testing the two legs (Coughlan et al, 2012). Reach distance was normalised to limb length using the maximised reach distance formula (distance/limb length) x 100 (Coughlan et al, 2012). This was done in order to account for leg-length differences in individuals (Coughlan, et al., 2012). The fourth trial was analysed for reach direction as well as for the overall analysis of performance (Fullam et al, 2014).

### 3.4.2 Three- dimensional kinematics analysis

The lower extremity 3D kinematics was captured using 12 Optitrack (Natural Poinnt, Oregon, USA) high-speed cameras, capturing 240 frames per second. These cameras were arranged around a capture space which was large enough to capture all movements in all three SEBT reach directions. The data was recorded through the trajectories of retro-reflective markers placed on participants' skin bilaterally as follows: over the joint space between the fifth lumbar and the first sacral spinous processes; ASIS; PSIS; the greater trochanter; mid-thigh; medial and lateral femoral epicondyles; tibia; medial and lateral malleoli; heels; and first and fifth metatarsal heads (Farrokhi, Pollard, Souza, Chen, 2008).

Trajectory data from reflective markers was used to calculate joint movements (Farrokhi et al, 2008). Before the recordings, a dynamic and static calibration was completed using the Optitrack Arena software (Natural Poinnt, Oregon, USA) to establish calibration constants. The data was captured on AMASS software (C-Motion, USA).

### 3.4.3 Injury monitoring forms

#### 3.4.3.1 Definition of injury

Injuries were monitored for the entire 2015/2016 cricket season using an injury monitoring form that was self-developed (Appendix A). The definition used in this study was derived from the following consensus statement, which was developed by the collaboration of representatives from the major cricket playing countries in 2005 and was revised in 2016 by Orchard et al (2016, p. 1246): ‘A general time-loss injury is any injury (or illness) that would have resulted in a player being considered unavailable for match-play, irrespective of whether a match or training was actually scheduled’. However, the following definition was used to filter information valuable for the purpose of this study: An injury is defined as ‘a musculoskeletal condition that resulted in the loss of at least one day of sporting activity or that occurred during a sporting activity that required medical attention’ (Olivier et al, 2015, p. 20).

#### 3.4.3.2 Pre-season questionnaire

A pre-season questionnaire (Appendix B) was completed before the commencement of the SEBT and 3D kinematics. It requested information about playing position, limb dominance, workload, participation in other sport, the use of proprioceptive-altering strapping such as tape and braces, past and current injury information, as well as management of these injuries. The pre-season questionnaire was used to establish participant eligibility based on the inclusion and exclusion criteria. It was also used to establish relevant information about previous injuries that can be used when analysing results at the end of the season for example, to establish whether there is a relationship between other factors, such as previous injury and prediction of injury.

This questionnaire was filled out in the presence of the researchers and these questions did arise and were addressed verbally. The question of frequency of competitive games and the previous injuries were both in reference to the previous season.

### 3.4.3.3 Injuring monitoring questionnaire

The Injury monitoring questionnaire (Appendix A) included detailed questions regarding injury. This included type of injury; during which activity did the injury occur; management of the injury; missed time due to injury; whether the injury was recurrent; and mechanism of injury.

The questionnaire was reviewed by two musculoskeletal physiotherapy researchers, a clinical sports physiotherapist, a batsman and a bowler from the University of Johannesburg cricket team, in order to attain content validity. The test-retest reliability was established using five batsmen and five bowlers from the University of Johannesburg cricket team, who completed the questionnaire one week apart.

All forms were handwritten and handed back. None of the cricket players opted to email results back. There were no discrepancies between the answers of the initial form and the one handed back a week later. This was likely due to the simplicity of the forms and most answers were given by ticking the appropriate box. The only section that required some writing was the section requesting a brief explanation of how the injury occurred.

Furthermore, there was difficulty in retrieving the completed forms, as participants were all training at different times and occasionally at different locations.

These issues were resolved by changing the forms from being filled out either by hand or email, to telephonic conversations with the players. The form was read out to the participant, and they indicated which box to fill in, and gave a brief description as to how the injury was sustained. If the information was too brief the researcher asked for a further explanation, without leading any answers. The coaches, with the participants consent, provided the information on the number of training sessions and competitive games which took place per week and if any of the participants had missed either.

## 3.5 Procedure

### 3.5.1 Pilot study

The aim of the pilot study was to allow the assessors to familiarise themselves with the equipment, and to assess the time needed to complete the main study testing, as well as to determine shortcomings, and detect bias before the main study began. Three participants who met the inclusion criteria were recruited for the pilot study which took place at the Wits Physiotherapy Movement Analysis Laboratory at the University of the Witwatersrand, Parktown, Johannesburg. The procedure was then followed as described in the main study.

The reach distances of every participant in all three directions were recorded by two researchers to test the inter-rater reliability. The participants performed the SEBT four times in each direction and each trial's reach distance was recorded in order to test the intra-rater reliability.

The pilot study revealed it would take at least thirty minutes per participant for the whole procedure to be completed and this was used in the planning of the main study. No major challenges were encountered during the pilot study and thus no changes were made to the procedure of the main study. Therefore, the pilot and the main study used the same methodology.

### 3.5.2 Main Study

Ethical clearance was obtained from The Human Research Ethics Committee (Medical) at the University of the Witwatersrand. Clearance certificate no: M150463 (Appendix F).

Permission was granted by the Highveld Lions, the Gauteng Strikers and the Gauteng Provincial under-19 teams management, following an information sheet that was handed to both the management and the cricket players (Appendix D), to approach their players to participate in the study and to conduct the study on their premises. Informed written consent was obtained by the participants prior to testing (Appendix E). Participation was voluntary, and all data captured and used did not identify individual participants, as they were converted into study numbers once the

data was captured on Microsoft Excel. Participants could withdraw from the study at any time without any repercussions.

All players in the Highveld Lions, Strikers and Gauteng U-19 teams were invited to participate in the study after receiving consent from management to approach the teams. All participants received verbal information about the study with regards to the aim, the significance, and their requirements.

A pre-set date and time for testing was established, and the participants that volunteered for the study were required to sign consent and complete the baseline questionnaire. This questionnaire was also used to determine eligibility.

The SEBT and the cameras for the Optitrack kinematic system were set up beforehand and the system was calibrated.

Participants were selected at random and asked to fill out the pre-season questionnaire. After completing the pre-season questionnaire, the participant's leg length was measured. The participant was asked to perform three hip bridges, to equalise the pelvis, then passively straightened the participant's legs and measured the distance from the ASIS to the distal aspect of the medial malleolus, using a standard tape measure, while the participant lay in supine on a plinth (Jamaluddin, et. al, 2011, Gribble, et al. 2013). The true leg length was then recorded and used in the normalisation of SEBT distances.

Prior to reflective marker placement, the skin was shaved and cleaned, using rubbing alcohol. The markers were stuck onto the anatomical sites previously mentioned, using two-way tape.

The participant had both verbal instructions as well as a demonstration of how to perform the SEBT. The participant selected which leg they wanted to begin the test with, at random. They then completed four trials of the SEBT and the kinematic recording system was activated before the participant began their final trial. They started with the anterior direction, followed by the postero-medial, then the postero-lateral direction. A two minute rest period was given before the process was repeated with the other leg in the same order. The distance was recorded where the

participant was able to maximally reach with a toe-touch and the standing leg's heel did not lift. All the SEBT data was recorded on a data sheet and kinematic data was recorded on a laptop with the software (Appendix C).

The participant was then monitored for injuries, and was contacted via WhatsApp, Facebook, phone call or communicated in person, to confirm whether they had sustained an injury in the lower back or lower limb, and the details thereof, as discussed in the questionnaire.

### 3.6 Data Reduction and Statistical Analysis

Data was captured on an Excel spreadsheet. Means and standard deviations were calculated for the baseline characteristics of injury epidemiology and the SEBT.

Limb length was used to normalise maximum reach distance in the anterior, postero-medial and postero-lateral directions to allow fair comparisons between participants. To express reach distance as a percentage of limb length, the normalised value was calculated as reach distance, divided by limb length, and multiplied by 100. Composite reach distance was the sum of the three reach directions, divided by three times limb length, and multiplied by 100.

Correlations between testers and between trials in order to determine inter-rater and intra-rater reliability, respectively, were calculated using Pearson's' correlation co-efficient. $p<0.05$ defined statistical significance.

All 22 participants' data was used in the analysis of the SEBT. Levene's and Shapiro-Wilk tests were used to determine if the assumption of homogeneity and normality were met, in order to classify data as parametric or non-parametric. The data was split into groups of dominant and non-dominant limbs, injured and non-injured limbs and in the anterior, postero-medial and postero-lateral directions. Descriptive statistics were used to describe the continuous variables of SEBT reach distances and categorical variables of injured and non-injured participants. Furthermore, a difference between groups was tested using the independent Student and paired samples t-tests (parametric) and the Mann-Whitney *U* test (non-parametric data). For the t-tests, effect size is given by Cohen's *d* and was

interpreted as follows; 0.2=small, 0.5=medium and 0.8=large (Cohen, 1992).The Mann-Whitney *U* test, effect size is given by the rank biserial correlation. The description for the strength of the relationship was defined as r=0.00–0.25 as little or no relationship; r= 0.25-0.5 fair relationship; r=0.5-0.75 moderate to good relationship; r>0.75 good to excellent relationship (Portney and Watkins, 2009).

A receiver operating curve (ROC) was used to test the sensitivity and specificity of the SEBT. The area under the ROC curve (AUC) was used to measure how well the SEBT can distinguish between injured and non-injured participants (Hajian-Tilaki, 2013). The recommendations of Plisky et al, (2006) were used to determine cut-off value at four cm to maximise sensitivity and specificity. The test's accuracy was defined as follows: AUC <0.5 as non-informative; 0.5<AUC<0.7, less accurate; 0.7<AUC<0.9 moderately accurate; 0.9<AUC<1 highly accurate; and AUC=1 100% accurate (Greiner, Pfeiffer & Smith, 2000).

Kinematic angles were analysed using AMASS software. Due to missing markers in the trajectory of the movement, of the 22 participants who performed the SEBT on both the right and left limb, only 13 of the right limb and 11 of the left limb data was available for analysis. The markers were all present, unfortunately the camera did not pick all the markers up accurately and during the analysis of movement on the software the data of the remainder of the participants was insufficient for analysis. Six of the 11 injured participants' data was available for kinematic analyses. This decreased the sample size for the 3D kinematic analyses and unfortunately the participants were well into the season when the kinematic analyses were performed and could therefore not be re-collected. Twenty-four 3D kinematic videos were analysed in this study. The only participant who was included in the 3D kinematic analysis and stated he was left side dominant, also stated that he was right leg dominant during batting and bowling. Therefore, since the kinematic angle analysis focused on the lower limb, the data was divided into right and left leg categories instead of dominant and non-dominant, as used during the SEBT analysis where this was not the case for all participants.

Descriptive data was used to analyse the hip, knee and ankle angles at the lowest point of the squat. This occurred during greatest knee flexion and as a result the knee data was presented before the hip and ankle data. The kinematic angles were

calculated in the x; y and z axis. For the hip and the knee x=flexion/extension; y=abduction/adduction and z= internal/external rotation. For the ankle x=dorsiflexion/plantarflexion; y= inversion/eversion and z= abduction/adduction. The differences between the injured and non-injured participants in the anterior, postero-medial and postero-lateral directions for both the right and left leg were analysed. The Levene's test was significant for all kinematic data ($p<0.05$) suggesting a violation of equal variance, therefore, the data was categorised as non-parametric. As a result the Mann-Whitney *U* test was used and the effect size was given by the rank biserial correlation (*r*).

The regression model was performed through a binary logistic regression with a forward method in order to identify strength of group identification based on the abovementioned factors. Initially a correlation analysis was performed to determine which variables correlated with injury status. Those that were significant or had a correlation value equal to or above 0.125 were entered as independent variable (predictor) of injury status (dependent variable) to create models. A combination of significant factors were also analysed for their combined predictive effects. Statistical significance of the models was tested using Chi-square analyses ($p<0.05$). All missing data points were replaced with the mean value of that variable. Cox and Snell R and Nagelerke R values were subsequently used to determine the strength of the models against each other. The binary logistic regression was performed to estimate the probability of injury occurring.

# Chapter 4: Results

This chapter will present the results from the pilot study as well as the main study, including SEBT reach distances and kinematic analysis of the hip, knee and ankle movement. Furthermore, the relationship between the SEBT reach distances, hip, knee and ankle movement and injury will be established

## 4.1 Pilot study

Table 4.1 shows the inter- and intra-rater reliability of the SEBT in all three reach directions. Both intra- and inter- rater reliability showed a strong correlation.

Table 4.1 Inter- and intra- rater reliability of the SEBT (n=3)

| Variable | Inter-rater reliability | Intra-rater reliability |
|---|---|---|
| Anterior | 0.98 | 1 |
| Postero-medial | 0.85 | 0.99 |
| Postero-lateral | 0.95 | 1 |

## 4.2 Participants

Twenty-four cricketers volunteered to participate in this study which took place at the Wanderers cricket stadium in Illovo, Johannesburg, during the 2015/2016 cricket pre-season. At the end of the season 22 participants a mean age of 20.2 (SD= 3.8) completed the study. Both of the participants that dropped out the study were batsman. One had emigrated to play rugby and the other dropped out of competitive cricket. Of the remaining participants, bowlers and batsmen were evenly distributed. Bowlers (n= 9,  37.5%) were made up of 44.4% fast bowlers, 22.2% spin bowlers and 33.3% seam bowlers. Batsmen (n= 9, %= 37.5) of which 2 were also keepers. All-rounders (n= 6; %= 33) were made up of 4 fast bowlers and 2 spin bowlers.

## 4.3 Anthropometric and training data

The participants' profiles were as follows: Mean height of the participants was 180.4cm (SD= 10.6cm) and the mean weight 80.9kg (SD= 10.1kg). Nineteen were right side dominant and six were left side dominant. The participants train for a minimum average of 4.8 (SD=1.14) times per week and participate in a minimum mean of 1.8 (SD=0.9) competitive games per week. This information was obtained during the first weekly questionnaire that was performed telephonically together with workload information shared by the coaches with the participants consent.

## 4.4 The prevalence, incidence and nature of injuries amongst participants

### 4.4.1 Injury history

Fourteen (58.3%) of the 24 participants had a history of lower quarter injury. The total number of injuries sustained during the previous cricket season (2014/2015) was 20. All injuries were classified as non-impact injuries of which, 55% (n= 11) were lower limb injuries, 25% (n= 5) were lumbar injuries and 20% (n= 4) of the injuries were sustained to the upper limb.

### 4.4.2 Injuries sustained in the 2015/2016 season

Eleven of the 22 participants (n= 11) sustained a total of 17 injuries during the 2015/2016 cricket season. All injuries were non-impact in nature. The injuries were distributed as follows: 59% (n= 10) were lower limb injuries and 29.4% (n= 5) were lower back injuries. Two participants who had injured their lower limb also sustained upper limb injuries. The injuries were predominantly (n= 7 64%) muscular in nature followed by ligament injuries (n=3, 21.4%). One of the lower back injuries was a lumbar disc injury (n=1). Of the lower limb injuries 60% (n= 6) were sustained to the non-dominant side and 54% (n= 6) of the injured participants, had previously sustained a lower limb injury.

The mean time missed for lower limb injuries was 3 weeks (median= 3, range= 5). . Lumbar injuries resulted in a mean time loss of 11 weeks (median= 7, range= 22). This data was skewed due to a lumbar fracture that was sustained during the 2015/2016 cricket season period and resulted in 6 months of missed time.

### 4.5 Star Excursion Balance Test

The normalised reach distances of the whole group on the dominant and non-dominant side are shown in Table 4.2.

Table 4. 2 Normalised reach distance description of the whole group's dominant and non-dominant leg (n=22)

| | Anterior dominant (%) | Anterior non-dominant (%) | Postero-medial dominant (%) | Postero-medial non-dominant (%) | Postero-lateral dominant (%) | Postero-lateral non-dominant (%) | Composite score dominant (%) | Composite score non-dominant (%) |
|---|---|---|---|---|---|---|---|---|
| Mean | 106.9 | 103.8 | 88.1 | 86.5 | 88.2 | 87.6 | 94.4 | 92.6 |
| Std. Deviation | 15.0 | 18.4 | 13.3 | 14.9 | 10.4 | 13.9 | 9.9 | 12.4 |
| Median | 107.4 | 105.6 | 89.6 | 91.1 | 89.1 | 89.1 | 93.9 | 97.3 |
| Range | 63.1 | 78.8 | 56.3 | 53.5 | 47.3 | 45 | 44.9 | 46.5 |

Table 4.2 shows the mean reach distance for all directions is lower for the non-dominant leg compared to the dominant leg. However; the median for postero-medial and composite scores are higher for the non-dominant leg compared to the dominant leg. Overall the participants reached the furthest with both legs in the anterior direction. The reach distance for the dominant group is almost the same for the postero-medial and postero-lateral direction whereas, for the non-dominant leg, participants reached further in the postero-lateral direction compared to the postero-medial direction.

The normalised reach distances of the injured compared to non-injured group on the dominant side is shown in Table 4.3 and non-dominant side are shown in Table 4.4 (parametric) and Table 4.5 (non-parametric).

Table 4. 3 Normalised reach distance description of injured vs non-injured participants for dominant limb (n= 22) (parametric data)

| | Injured | | Non-injured | | | 95% CI for Cohen's *d* | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Mean (%) | SD (%) | Mean (%) | SD (%) | P Value | Cohen's *d* | Lower | Upper |
| Anterior dominant | 107.5 | 13.3 | 106.4 | 17.3 | 0.865 | 0.073 | -0.764 | 0.908 |
| Postero-medial dominant | 87.5 | 13.5 | 88.7 | 13.7 | 0.849 | 0.082 | -0.917 | 0.755 |
| Postero-lateral dominant | 88.6 | 7.1 | 87.7 | 13.3 | 0.839 | 0.088 | -0.749 | 0.923 |
| Composite scores dominant | 94.6 | 6.6 | 94.2 | 12.7 | 0.942 | 0.031 | -0.805 | 0.867 |

* denotes statistical significance ($p<0.05$); SD – Standard Deviation; CI – Confidence Interval

Table 4.3. illustrates the normalised reach distances of injured and non-injured participants for the dominant leg in all three reach directions as well as the composite score. The tests show no statistically significant results signifying no statistical differences are evident between injured and non-injured participants. However, the effect size for the anterior dominant is medium to good (Cohen's *d*=0.7), postero-medial and postero-lateral is good (Cohen's *d*=0.8).

Table 4. 4 Normalised reach distance description of injured vs non-injured participants for non-dominant limb (n=22) (parametric data)

| | Injured | | Non-injured | | | 95% CI for Cohen's *d* | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Mean (%) | SD (%) | Mean (%) | SD (%) | P Value | Cohen's *d* | Lower | Upper |
| Anterior non-dominant | 104.8 | 11.2 | 102.7 | 24.2 | 0.802 | 0.109 | -0.729 | 0.944 |
| Postero-medial non-dominant | Data not normally distributed – Non-parametric tests used (Table 4.4) | | | | | | | |
| Postero-lateral non-dominant | 90.1 | 13.0 | 85.0 | 14.8 | 0.402 | 0.365 | -0.483 | 1.204 |
| Composite score non-dominant | Data not normally distributed – Non-parametric tests used (Table 4.4) | | | | | | | |

* denotes statistical significance ($p<0.05$); SD – Standard Deviation; CI – Confidence Interval

Table 4.4 represents the normalised reach distance descriptions of injured and non-injured participants for non-dominant limb in the anterior and postero-lateral directions. The statistical test reveals that no statistically significant differences exist between injured and non-injured participant scores. There is a small effect size for the anterior direction (Cohen's *d*=0.1) and postero-lateral direction (Cohen's *d*=0.3).

Table 4. 5 Normalised reach distance description of injured vs non-injured participants for non-dominant limb (n=22) (non-parametric data)

| | Injured | | Non-injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Mean (%) | SD (%) | Mean (%) | SD (%) | P Value | Effect size (*r)* | Lower | Upper |
| Postero-medial non-dominant | 95.2 | 43.7 | 83.9 | 53.4 | 0.168 | 0.609 | -0.254 | 1.459 |
| Composite scores non-dominant | 95.0 | 37.6 | 88.9 | 60.8 | 0.324 | 0.431 | -0.42 | 1.272 |

* denotes statistical significance (p<0.05); SD – Standard Deviation; CI – Confidence Interval

Table 4.5 shows the normalised reach distances comparing injured and non-injured participants in the postero-medial direction, as well as the composite score for the non-dominant limb for data that is not normally distributed. Even though the effect size is moderate to good in the postero-medial direction ($r$=0.6) and the median reach distance of the injured group (95.2%) is longer than that of the non-injured group (83.9%) the tests are still not statistically significant.

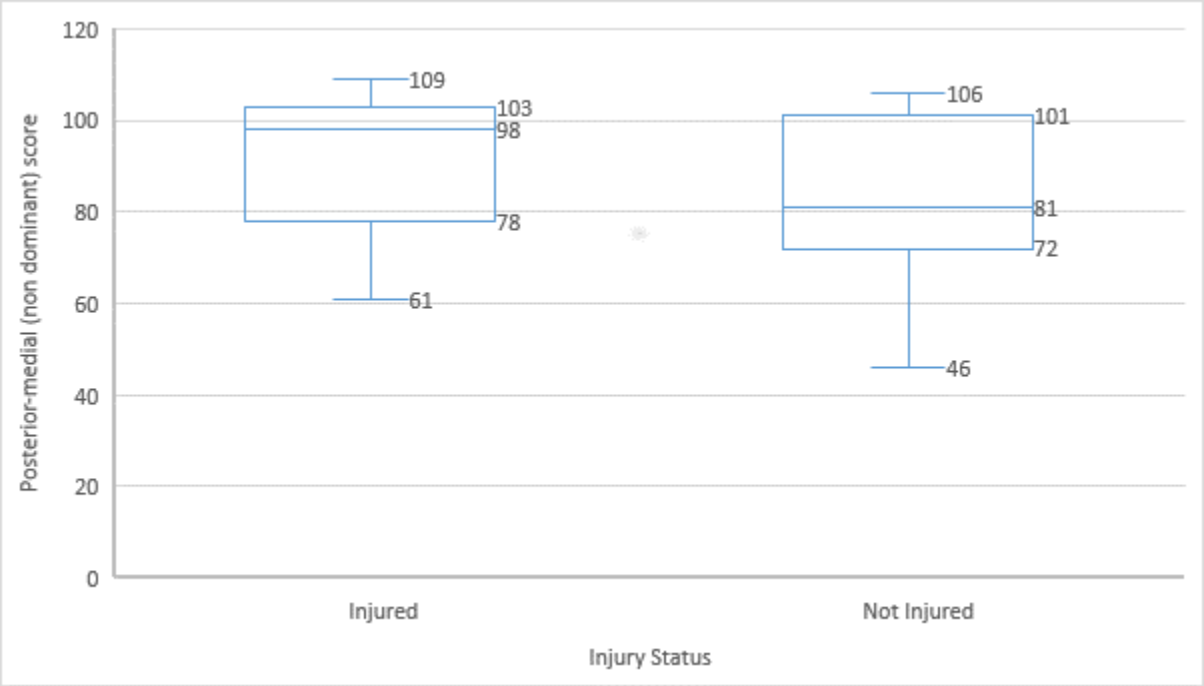



Figure 4. 1: Box plot of postero-medial non-dominant scores comparing injured and non-injured participants (n=22) (non-parametric)

The box plot shown in Figure 4.1 is used for non-parametric data to show the distribution of data for the postero-medial direction for the non-dominant limb (Table 4.5). This box plot shows sizeable difference in the spread of data between injured compared to non-injured participants. This finding was not statistically significant however; the effect size is moderate to good (biserial rank $r$=0.6) (Table 4.5). The median for injured participants is higher and the range is smaller when compared to non-injured participants.

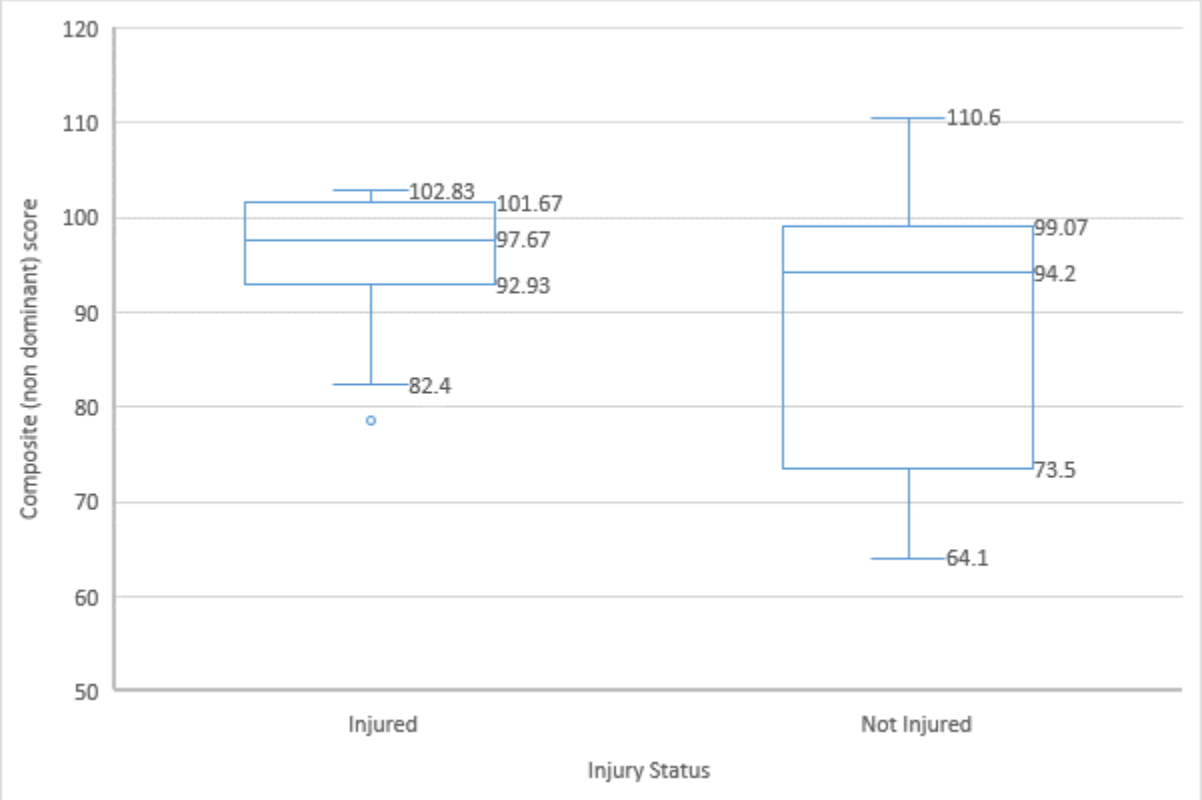



Figure 4. 2 Box plot showing composite non-dominant score comparing injured and non-injured participants on the non-dominant limb (n=22) (non-parametric)

The box plot shown in Figure 4.2 is used to show the distribution of data for the composite scores for the non-dominant limb (Table 4.5). There is a substantial difference in the spread of data between injured participants compared to non-injured participants; the range is smaller and the median for injured participants is higher compared to non-injured participants. Thus, in general, the scores for the injured participants are higher than that of non-injured participants. This finding is not statistically significant and the effect size is fair (biserial rank $r$=0.4) (Table 4.5).

The normalised reach distance for the dominant compared to non-dominant limb for injured participants is shown Table 4.6, and the non-injured participants in Table 4.7.

Table 4. 6 Normalised reach distance description comparing dominant and non-dominant limbs of injured participants (n=11) (parametric)

| | Dominant | | Non-dominant | | | 95% CI for Cohen's *d* | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Mean (%) | SD (%) | Mean (%) | SD (%) | P Value | Cohen's *d* | Lower | Upper |
| Anterior | 107.5 | 13.3 | 104.8 | 11.2 | 0.169 | 0.447 | -0.194 | 1.11 |
| Postero-medial | 87.5 | 13.5 | 90.9 | 12.3 | 0.461 | 0.231 | -0.865 | 0.392 |
| Postero-lateral | 88.6 | 7.1 | 90.1 | 13.0 | 0.669 | 0.133 | -0.759 | 0.487 |
| Composite scores | 94.6 | 6.6 | 95.3 | 8.0 | 0.665 | 0.134 | -0.76 | 0.485 |

* denotes statistical significance ($p<0.05$); SD – Standard Deviation; CI – Confidence Interval

Table 4.6. shows no statistical significant results from the independent samples t-test when comparing the dominant and non-dominant limb of injured participants. In general, there is little effect size with the exception of the anterior direction where the effect size is moderate (Cohen's *d*=0.4). The mean of the dominant limb in the anterior direction (107.5%) is more than the non-dominant limb (104.8%). However, the mean of the postero-medial, postero-lateral and composite scores are all larger in the non-dominant limb compared to the dominant limb.

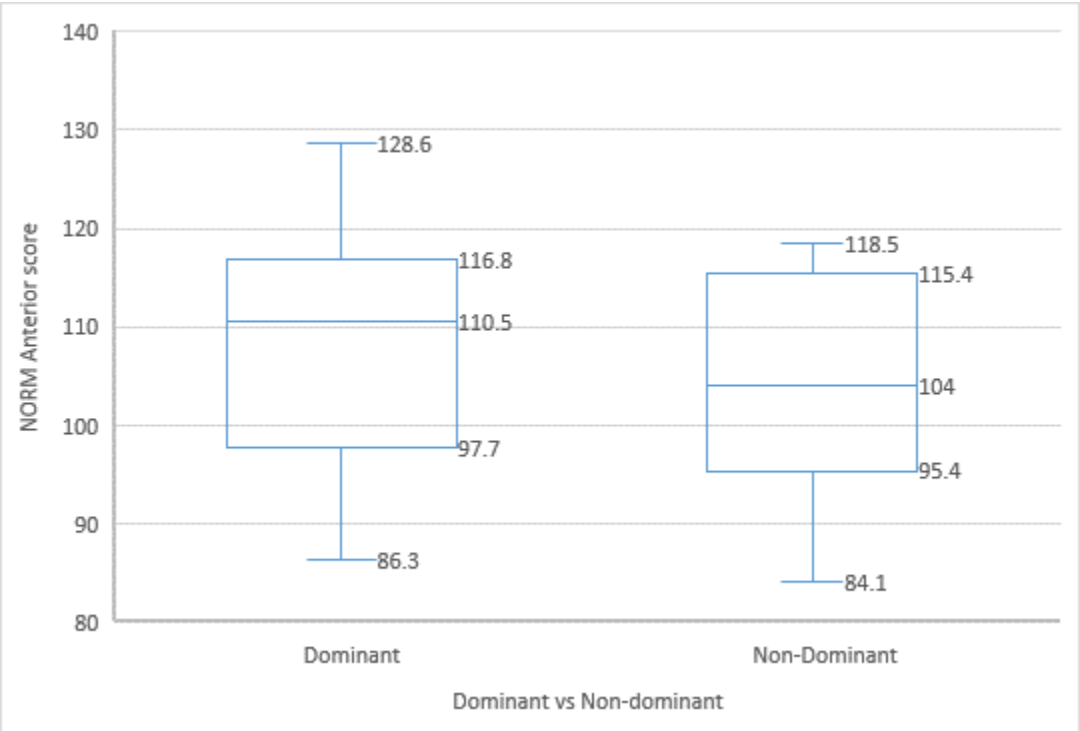



Figure 4. 3 Box plot showing anterior reach distance scores for dominant compared to non-dominant limbs for injured participants (n=11)

The box plot shown in Figure 4.3 shows the median scores for the anterior direction comparing the dominant and non-dominant limb of injured participants. There are no statistically significant results. However, the box plot illustrates the median reach distance for the dominant limb is higher than that of the non-dominant limb and the range is smaller for the non-dominant limb compared to the dominant limb.

The normalised reach distance for the dominant compared to non-dominant limb for the non-injured participants are shown in Table 4.7.

Table 4. 7 Normalised reach distance description comparing dominant and non-dominant limbs of non-injured participants (n=11) (parametric)

| | Dominant | | Non-dominant | | | 95% CI for Cohen's *d* | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Mean (%) | SD (%) | Mean (%) | SD (%) | P Value | Cohen's *d* | Lower | Upper |
| Anterior | 106.4 | 17.3 | 102.7 | 24.2 | 0.298 | 0.331 | -0.299 | 0.977 |
| Postero-medial | 88.7 | 13.7 | 82.1 | 16.5 | 0.089 | 0.567 | -0.089 | 1.254 |
| Postero-lateral | 87.7 | 13.3 | 85.0 | 14.8 | 0.456 | 0.234 | -0.39 | 0.868 |
| Composite scores | 94.2 | 12.7 | 89.9 | 15.6 | 0.092 | 0.562 | -0.093 | 1.247 |

* denotes statistical significance ($p<0.05$); SD – Standard Deviation; CI – Confidence Interval

All three reach directions are represented in Table 4.10, anterior (106.4%), postero-medial (88.7%), postero-lateral (87.7%) and the composite scores (94.2%) have further reach distances in the dominant limb compared to the non-dominant limb (102.7%, 82.1%, 85.0% and 89.9%) respectively. There is no significant difference between dominant and non-dominant scores and the effect sizes are small to medium for the anterior (Cohen's *d*= 0.3) and postero-lateral directions (Cohen's *d*= 0.2). The postero-medial direction (Cohen's *d*= 0.5) and the composite scores (Cohen's *d*= 0.5) however, have a medium effect size.

### 4.6 Receiver Operating Curve

Table 4. 8. Receiver operating curve area under the curve of the SEBT normalised reach distances for the dominant and non-dominant limb (n=22)

| Direction | Area under the curve (AUC) | Standard. Error | Asymptotic Significance | Asymptotic 95% CI | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Anterior dominant | 0.55 | 0.13 | 0.670 | 0.67 | 0.30 |
| Postero-medial dominant | 0.43 | 0.13 | 0.577 | 0.58 | 0.18 |
| Postero-lateral dominant | 0.50 | 0.13 | 0.974 | 0.97 | 0.24 |
| Composite scores dominant | 0.48 | 0.13 | 0.896 | 0.90 | 0.23 |
| Anterior non-dominant | 0.68 | 0.12 | 0.158 | 0.16 | 0.44 |
| Postero-medial non-dominant | 0.61 | 0.12 | 0.375 | 0.38 | 0.37 |
| Postero-lateral non- dominant | 0.60 | 0.13 | 0.450 | 0.45 | 0.35 |
| Composite scores non-dominant | 0.46 | 0.13 | 0.768 | 0.77 | 0.20 |

* CI – Confidence Interval

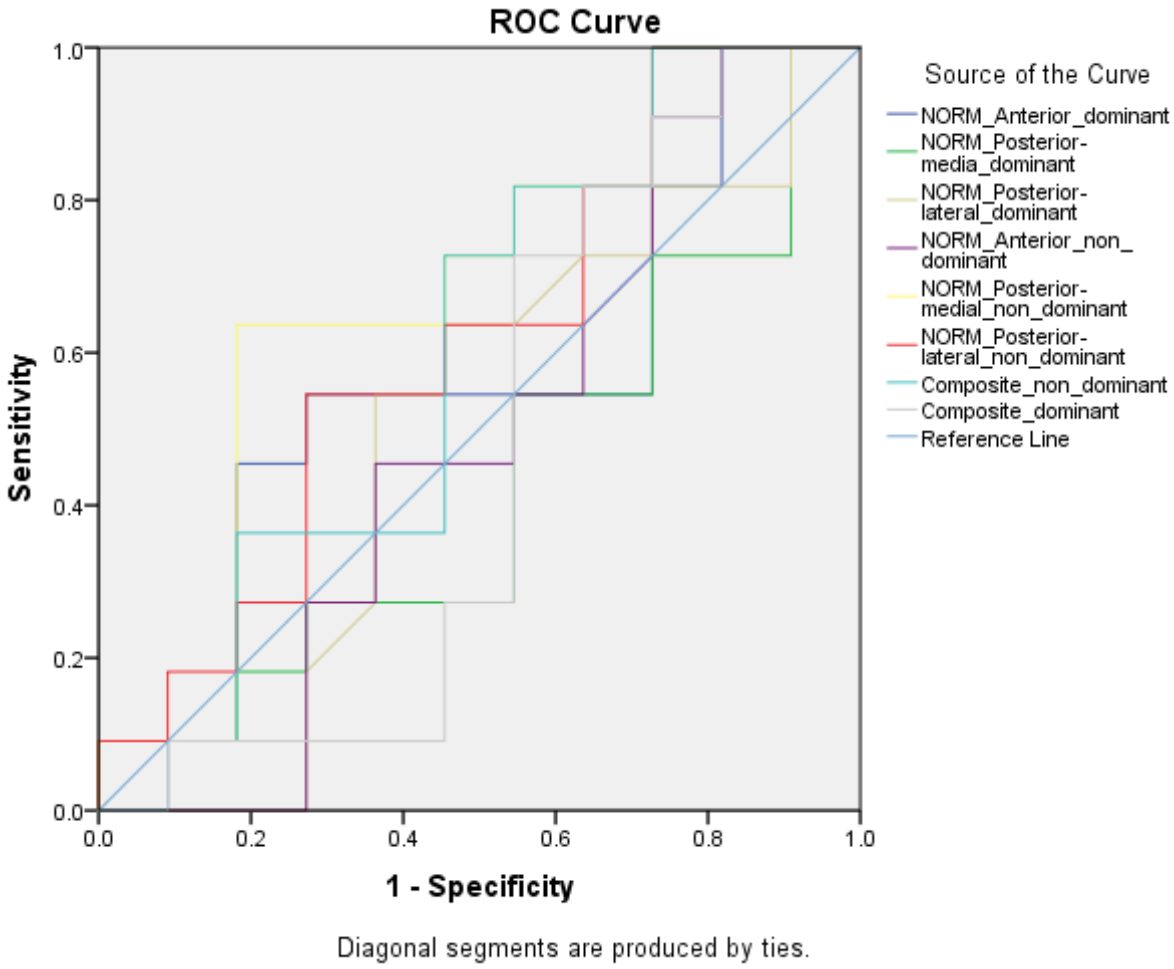



Figure 4. 4 Receiver operating characteristic for SEBT dominant and non-dominant scores

The ROC in Figure 4.4 shows none of the measures (dominant or non-dominant) achieved statistical significance. The area under the curve (AUC) (Table 4.8) for the SEBT in the postero-medial direction (AUC=0.6), postero-lateral direction (AUC=0.6) and composite score (AUC=0.6) for the non-dominant limb and the anterior reach direction for the dominant limb (AUC=0.5) achieved less accurate ratings as an instrument to measure injury status. All the other reach directions for both the dominant and non-dominant limb achieved non informative ratings. Findings of sensitivity and specificity are discussed in detail in the discussion.

### 4.7. Kinematic angles

#### 4.7.1 Kinematic angles during the Star Excursion Balance Test

The kinematic hip, knee and ankle angles, at the lowest point of the squat, during the SEBT for the right leg are shown in Table 4.9 and Table 4.10 for the left leg.

Table 4. 9 Kinematic angles at the lowest level of squat for injured and non-injured participants for the right leg (n=13)

| Right | | Mean (°) | Median (°) | Std. Deviation (°) | Range (°) | Minimum (°) | Maximum (°) |
|---|---|---|---|---|---|---|---|
| Knee flexion | Injured | 51.00 | 53.01 | 7.15 | 18.25 | 41.30 | 59.55 |
| | Non-injured | 58.80 | 57.78 | 18.42 | 52.86 | 26.02 | 78.88 |
| Knee Abduction | Injured | -<0.001- | -<0.001 | <0.001 | <0.001 | -<0.001 | 0.001 |
| | non-injured | -<0.001 | -<0.001 | <0.001 | <0.001 | -<0.001 | <0.001 |
| Knee Internal rotation | Injured | -<0.001 | -<0.001 | <0.001 | <0.001 | -<0.001 | <0.001 |
| | Non-injured | -<0.001 | 0 | <0.001 | <0.001 | -<0.001 | <0.001 |
| Hip Flexion | Injured | 64.73 | 70.90 | 37.64 | 104.30 | 8.09 | 112.40 |
| | Non-injured | 79.28 | 79.57 | 8.87 | 28.86 | 64.02 | 92.88 |
| Hip Abduction | Injured | -13.05 | -12.22 | 18.30 | 48.79 | -40.81 | 7.98 |
| | Non-injured | -0.22 | -0.63 | 10.68 | 29.23 | -16.38 | 12.85 |
| Hip Internal Rotation | Injured | -21.33 | -20.81 | 21.38 | 64.98 | -58.94 | 6.04 |
| | Non-injured | -11.12 | -7.56 | 19.43 | 54.05 | -43.56 | 10.50 |
| Ankle Dorsiflexion | Injured | 85.09 | 85.95 | 7.24 | 19.30 | 76.83 | 96.13 |

| Right | | Mean (°) | Median (°) | Std. Deviation (°) | Range (°) | Minimum (°) | Maximum (°) |
|---|---|---|---|---|---|---|---|
| | Non-injured | 90.08 | 91.00 | 13.82 | 41.79 | 66.52 | 108.30 |
| Ankle Inversion | Injured | 4.40 | 4.55 | 3.87 | 10.10 | -0.11 | 9.99 |
| | Non-injured | 3.60 | 7.41 | 11.76 | 35.08 | -17.66 | 17.42 |
| Ankle Abduction | Injured | -20.45 | -20.82 | 3.99 | 11.82 | -24.87 | -13.06 |
| | Non-injured | -11.20 | -13.31 | 7.56 | 20.75 | -20.58 | 0.17 |

Table 4.9 represents the lower limb kinematics for injured and non-injured participants. Large hip flexion angles (injured=64.73°; non-injured=79.28°), knee flexion angles (Injured=51.00°; non-injured=58.80°) and ankle dorsiflexion angles (Injured=85.09°; non-injured=90.08°) are evident. Hip rotation angles (injured=11.12°; non-injured=21.33°) and ankle abduction angles (injured=20.45°; Non-injured=11.20°) are also relatively large. In contrast, knee abduction (injured= 0.000000167°; non-injured= 0.000000429°) and rotation angles (injured=0.000001°; non-injured=0.000000571°) are very small.

Table 4. 10 Kinematic angles at the lowest level of squat for injured and non-injured participants for the left leg (n=11)

| Left | | Mean (°) | Median (°) | Std. Deviation (°) | Range (°) | Minimum (°) | Maximum (°) |
|---|---|---|---|---|---|---|---|
| Knee flexion | Injured | 56.69 | 53.91 | 11.75 | 31.68 | 40.69 | 72.37 |
| | Non-injured | 51.36 | 47.46 | 17.37 | 44.90 | 32.61 | 77.51 |
| Knee Abduction | Injured | 0.1728 | <0.001 | 0.3864 | 0.864 | <0.001 | 0.864 |
| | Non-injured | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Knee Internal rotation | Injured | -1.106 | -0.001 | 2.473 | 5.529 | -5.529 | <0.001 |
| | Non-injured | -<0.001 | -0.001 | 0.001 | 0.001 | -0.001 | 0.001 |
| Hip Flexion | Injured | 71.99 | 71.40 | 12.55 | 26.80 | 59.18 | 85.98 |
| | Non-injured | 72.59 | 69.44 | 11.52 | 31.37 | 60.43 | 91.80 |
| Hip Abduction | Injured | -3.28 | -5.59 | 21.22 | 51.51 | -26.72 | 24.79 |
| | Non-injured | -3.46 | -2.15 | 14.14 | 40.97 | -29.60 | 11.37 |
| Hip Internal Rotation | Injured | 26.69 | 22.77 | 15.21 | 31.87 | 14.67 | 46.54 |
| | Non-injured | 11.17 | 4.72 | 20.80 | 56.86 | -5.62 | 51.24 |
| Ankle Dorsiflexion | Injured | 85.76 | 85.84 | 3.26 | 7.54 | 82.26 | 89.80 |

| Left | | Mean (°) | Median (°) | Std. Deviation (°) | Range (°) | Minimum (°) | Maximum (°) |
|---|---|---|---|---|---|---|---|
| | Non-injured | 79.95 | 84.62 | 13.15 | 35.40 | 56.05 | 91.45 |
| Ankle Inversion | Injured | 8.31 | 1.49 | 11.65 | 24.11 | -2.80 | 21.31 |
| | Non-injured | -3.05 | -5.60 | 17.76 | 46.28 | -24.72 | 21.56 |
| Ankle Abduction | Injured | 46.64 | 14.91 | 68.12 | 155.50 | 12.81 | 168.30 |
| | Non-injured | 34.49 | 6.56 | 68.58 | 174.80 | -0.97 | 173.80 |

Table 4.10 represents the lower limb kinematic angles for the left leg and similarly, the right leg also shows large hip (injured=71.99°; non-injured=72.59°), knee (injured=56.69°; non-injured=51.36°) and ankle flexion angles (Injured=85.76°; non-injured=79.95°). Surprisingly hip abduction angles are relatively small for the left limb (injured=3.3°; non-injured=3.5°) (Table 4.10).

The kinematic angles description comparing injured and non-injured participants in the anterior, postero-medial and postero-lateral direction during the lowest point of the squat in each direction with the standing right leg is represented in Table 4.11, Table 4.12 and Table 4.13 respectively.

Table 4. 11 Kinematic angles description for anterior direction comparing injured and non-injured participants for right leg (n=13) (non-parametric)

| Right | Injured | | Non-Injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Anterior | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 14.81 | 32.42 | 17.62 | 53.86 | 0.628 | 0.190 | -0.689 | 0.430 |
| Knee Abduction | <0.001 | <0.001 | <0.001 | <0.001 | 0.190 | 0.600 | -0.107 | 0.904 |
| Knee Internal Rotation | <0.001 | <0.001 | <0.001 | <0.001 | 0.286 | 0.500 | -0.246 | 0.874 |
| Hip Flexion | -1.60 | 56.74 | -19.44 | 35.18 | 0.101 | 0.571 | -0.004 | 0.862 |
| Hip Abduction | -1.39 | 38.49 | -6.70 | 33.89 | 0.366 | 0.333 | -0.297 | 0.762 |
| Hip Internal rotation | 6.37 | 34.62 | -5.78 | 27.88 | 0.073 | 0.657 | 0.098 | 0.901 |
| Ankle Dorsiflexion | 92.05 | 26.17 | 102.30 | 29.92 | 0.050 | 0.667 | -0.897 | -0.150 |
| Ankle Inversion | 7.76 | 14.21 | 12.35 | 25.65 | 0.530 | 0.257 | -0.741 | 0.402 |
| Ankle Abduction | -23.31 | 11.53 | -14.67 | 16.14 | 0.035* | 0.714 | -0.914 | -0.238 |

Table 4.11 represents the kinematic angles description of the right leg hip, knee and ankle angles in the anterior direction. Statistical tests revealed significant difference found between the injured and non-injured group for ankle abduction angles in the anterior direction (p=0.035) with a moderate to good effect size (biserial rank *r*=0.7). Participants in the injured group exhibited larger ankle abduction angles (23.3°) than the non-injured group (14.7°). Although not statistically significant, the effect size for knee abduction (biserial rank *r*=0.6), hip flexion (biserial rank *r*=0.6), hip external rotation (biserial rank *r*=0.7) and ankle dorsiflexion (biserial rank *r*=0.7) are all moderate to good.

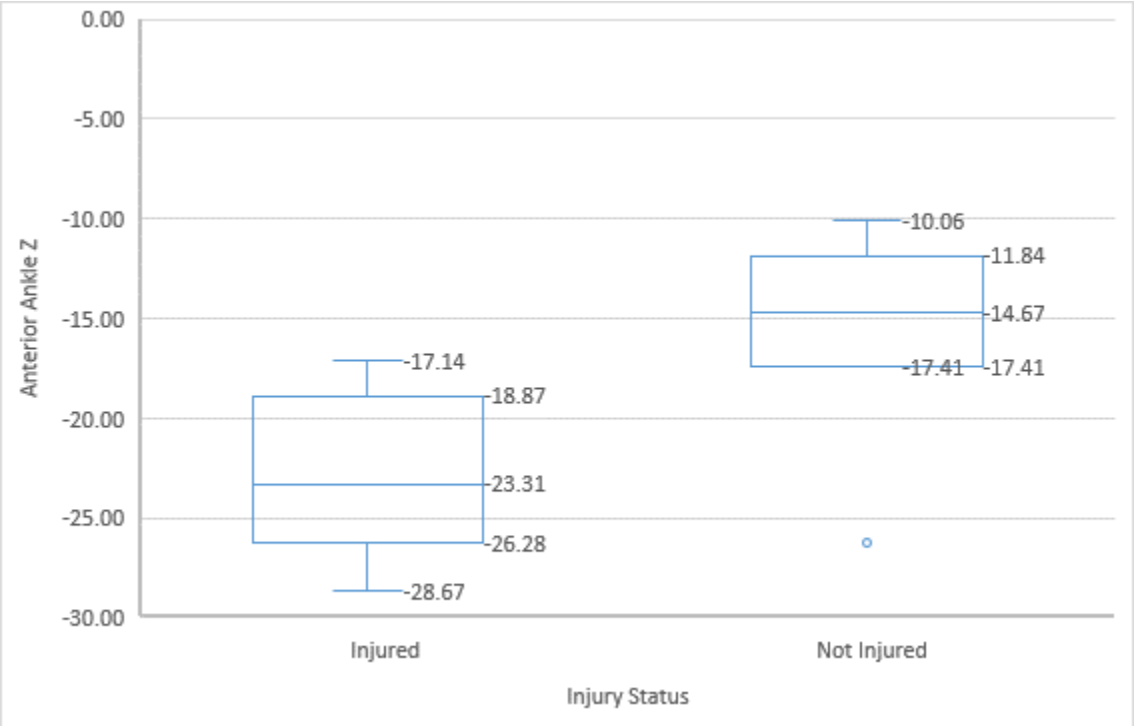



Figure 4. 5 Box plot showing the ankle abduction angles for the anterior reach direction comparing injured and non-injured participants for the right leg (n=13) (non-parametric).

The box plot shown in Figure 4.5 is used to show the distribution of data for the statistically significant ankle abduction angles in the anterior direction (p=0.035) (Table 4.11). A noticeable difference in the spread of data between injured and non-injured participants is evident. The injured participants have a larger angle median (23.3°) compared to the non-injured group (14.7°). The range, however, is smaller in the injured group (11.53°) compared to the non-injured group (16.14°) (Table 4.11).

Table 4. 12 Kinematic angles description for postero-medial direction comparing injured and non-injured participants for right leg (n=13) (non-parametric)

| Right | Injured | | Non-Injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Postero- medial | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 35.35 | 28.54 | 39.81 | 41.18 | 0.394 | 0.333 | -0.773 | 0.322 |
| Knee Abduction | -<0.001 | <0.001 | <0.001 | <0.001 | 0.008* | 1.000 | -1.000 | -1 |
| Knee Internal Rotation | <0.001 | <0.001 | <0.001 | <0.001 | 0.690 | 0.200 | -0.741 | 0.499 |
| Hip Flexion | 67.67 | 67.77 | 74.59 | 14.93 | 0.662 | 0.200 | -0.725 | 0.472 |
| Hip Abduction | 13.62 | 37.31 | 12.73 | 26.59 | 1.000 | 0.000 | -0.592 | 0.592 |
| Hip Internal rotation | -44.88 | 74.74 | -43.77 | 38.69 | 0.818 | 0.111 | -0.659 | 0.514 |
| Ankle Dorsiflexion | 71.95 | 19.11 | 78.57 | 39.67 | 0.485 | 0.278 | -0.747 | 0.375 |
| Ankle Inversion | -8.22 | 18.89 | -8.05 | 19.75 | 0.699 | 0.167 | -0.471 | 0.69 |
| Ankle Abduction | 13.62 | 37.31 | 12.73 | 26.59 | 1.000 | 0.000 | -0.592 | 0.592 |

* denotes statistical significance (p<0.05); CI – Confidence Interval

Table 4.12 reveals statistically significant differences between the injured and non-injured participants' knee abduction angles in the postero-medial direction (p=0.008) with an excellent effect size (biserial rank *r* =1). However, both angles were very small and therefore, clinically insignificant as there is no way to measure such small angles. The effect size for all the other angles are little to fair with no other statistically significant differences noted.

Table 4. 13 Kinematic angles description for postero- lateral direction comparing injured and non-injured participants for right leg (n=13) (non-parametric)

| Right | Injured | | Non-Injured | | Rank biserial correlation CI | | | |
|---|---|---|---|---|---|---|---|---|
| Postero- lateral | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 40.25 | 26.49 | 55.38 | 67.09 | 0.366 | 0.333 | -0.762 | 0.297 |
| Knee Abduction | <0.001 | 7.12 | -<0.001 | 0.31 | 0.945 | 0.048 | -0.605 | 0.541 |
| Knee Internal Rotation | <0.001 | <0.001 | <0.001 | <0.001 | <0.111 | 0.700 | -0.931 | -0.067 |
| Hip Flexion | 58.39 | 79.70 | 69.41 | 59.44 | 1.000 | 0.000 | -0.574 | 0.574 |
| Hip Abduction | -12.43 | 46.25 | -5.67 | 38.92 | 0.234 | 0.429 | -0.805 | 0.193 |
| Hip Internal rotation | 5.69 | 32.32 | -7.78 | 40.28 | 0.106 | 0.600 | 0.004 | 0.882 |
| Ankle Dorsiflexion | 83.37 | 23.87 | 85.30 | 59.43 | 0.836 | 0.095 | -0.634 | 0.506 |
| Ankle Inversion | 3.61 | 7.82 | 12.83 | 17.64 | 0.101 | 0.571 | -0.862 | 0.004 |
| Ankle Abduction | -22.85 | 12.48 | -12.31 | 18.17 | 0.022* | 0.762 | -0.929 | -0.334 |

* denotes statistical significance (p<0.05); CI – Confidence Interval.

Table 4.13 represents the kinematic angles description of the right hip, knee and ankle angles in the postero-lateral directions. Statistical tests revealed significant difference found between the injured and non-injured group for ankle abduction angles (p=0.02) with a moderate to good effect size (biserial rank *r*=0.8) (Table 4.13). Even though moderate to good effect sizes are found in the knee external rotation (biserial rank *r*=0.7), hip external rotation (biserial rank *r*=0.6) and ankle eversion (biserial rank *r*=0.6) in the postero-lateral direction, they are not statistically significant (Table 4.13).

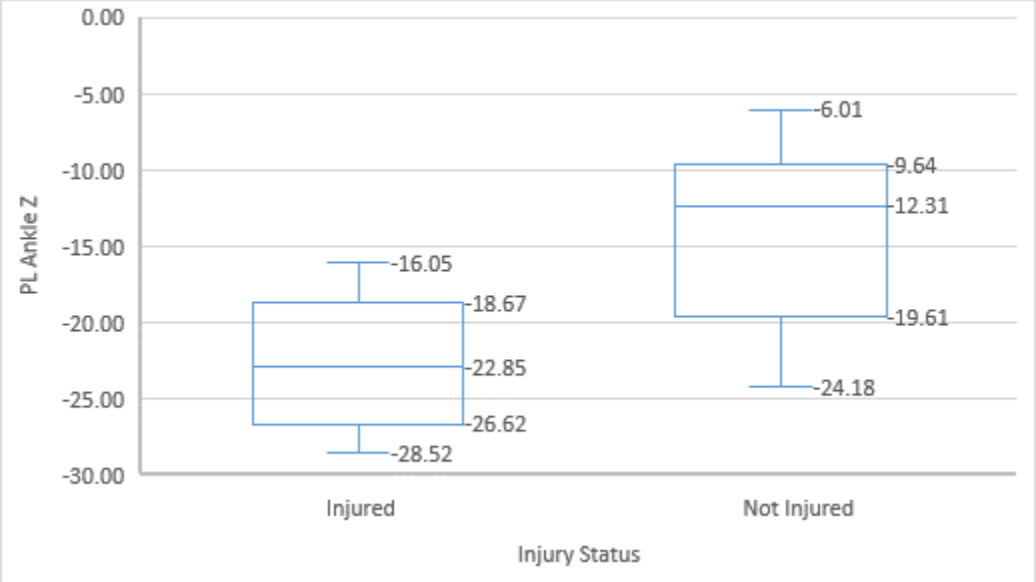



Figure 4. 6 Box plot showing the ankle abduction angles for the postero-lateral direction comparing injured non-injured participants for the right leg (n=13) (non-parametric).

The box plot shown in Figure 4.7 illustrates show ankle abduction angles in the postero-lateral direction of the right leg (Table 4.13). The differences between the injured and non-injured participants is statistically significant (p=0.022) and has a good to excellent effect size (biserial rank *r*=0.8) (Table 4.13). Ankle abduction angles in the injured group (22.9°) are larger than the non-injured group (12.3°), however, the range is larger in the non-injured group (18.2°) compared to the injured group (12.5°) (Table 4.13).

The kinematic angle description comparing injured and non-injured participants in the anterior, postero-medial and postero-lateral direction during the lowest point of the squat in each direction, for the standing left leg is represented in Table 4.14, Table 4.15 and Table 4.16 respectively.

4. 14 Kinematic angles description for anterior direction comparing injured and non-injured participants for left leg (n=11) (non-parametric)

| Left | Injured | | Non-Injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Anterior | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 13.87 | 36.13 | 14.22 | 23.31 | 0.731 | 0.143 | -0.470 | 0.662 |
| Knee Abduction | 0.00 | 0.00 | 0.00 | 0.00 | 0.486 | 0.375 | -0.846 | 0.426 |
| Knee Internal Rotation | 0.51 | 2.98 | 0.00 | 0.09 | 0.295 | 0.381 | -0.247 | 0.784 |
| Hip Flexion | -13.33 | 24.30 | -24.63 | 14.99 | 0.073 | 0.619 | 0.070 | 0.880 |
| Hip Abduction | -2.44 | 27.19 | 2.65 | 7.42 | 0.065 | 0.667 | -0.902 | -0.124 |
| Hip Internal rotation | -7.04 | 17.56 | -0.03 | 27.02 | 0.101 | 0.571 | -0.862 | 0.004 |
| Ankle Dorsiflexion | 88.46 | 41.39 | 91.90 | 26.60 | 0.234 | 0.429 | -0.805 | 0.193 |
| Ankle Inversion | 0.57 | 20.45 | -0.06 | 25.85 | 0.945 | 0.048 | -0.541 | 0.605 |
| Ankle Abduction | 17.15 | 13.66 | 8.95 | 11.35 | 0.03* | 0.800 | 0.365 | 0.948 |

* denotes statistical significance ($p<0.05$); CI – Confidence Interval

Table 4.14 shows statistically significant differences in the ankle abduction angles in the injured and non-injured groups (p = 0.003) with a good to excellent effect size (biserial rank *r=0*.8). The injured median (17.15°) and range (13.66°) are larger compared to the non-injured participants' median (8.948°) and range (11.35°). Although not significant, the effect size of the hip abduction angles (biserial rank *r*=0.6) and hip flexion angles (biserial rank *r*=0.6) are moderate to good.

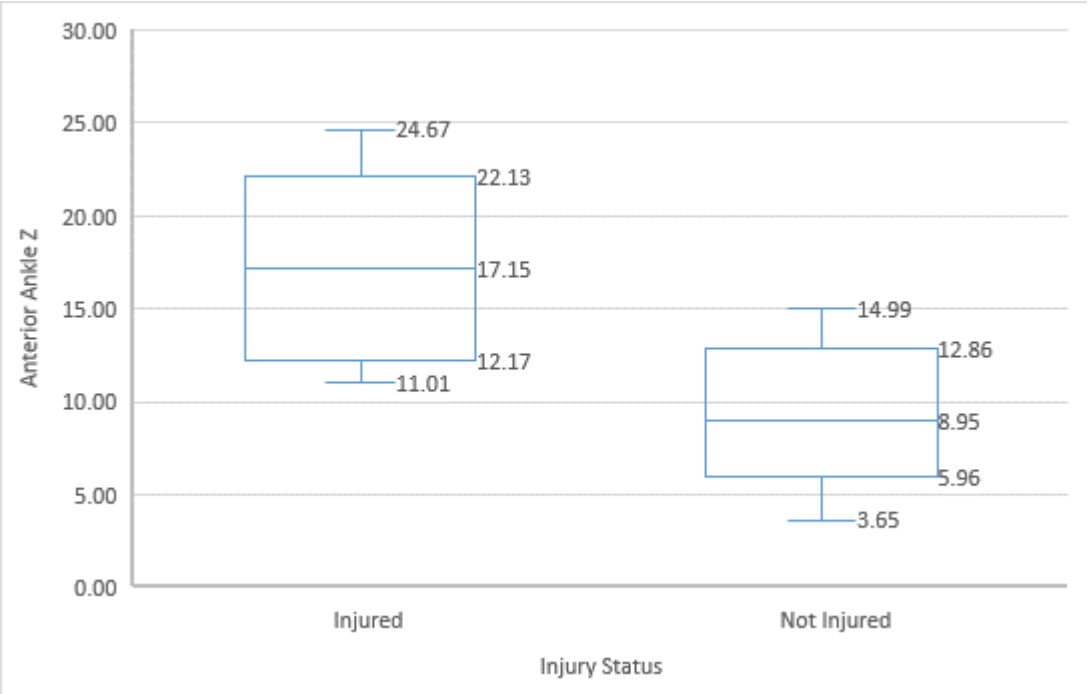



Figure 4. 7 Box plot showing the ankle abduction angles for the postero-lateral direction comparing injured and non-injured participants for the left leg (n=11) (non-parametric)

The box plot in Figure 4.8 clearly illustrates the larger ankle abduction angles in the injured group (17.15°) compared to the non-injured group (8.95°). The range is also noticeably larger in the injured compared (13.66°) to the non-injured group (11.35°). These results are statistically significant (p=0.003) and have a good to excellent effect size (biserial rank *r*=0.8) (Table 4.14)

Table 4. 15 Kinematic angles description for postero-medial direction comparing injured and non-injured participants for left leg (n=11) (non-parametric)

| Left | Injured | | Non-Injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Postero-medial | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 37.97 | 15.24 | 30.55 | 45.97 | 0.485 | 0.278 | -0.375 | 0.747 |
| Knee Abduction | 0.001 | 0.001 | -0.001 | 0.001 | 1.000 | 0.040 | -0.611 | 0.659 |
| Knee Internal Rotation | -0.001 | 0.001 | 0.001 | 0.001 | 0.421 | 0.360 | -0.810 | 0.357 |
| Hip Flexion | 73.39 | 28.44 | 62.45 | 34.95 | 0.180 | 0.500 | -0.130 | 0.842 |
| Hip Abduction | -13.72 | 26.81 | -13.23 | 13.94 | 1.000 | 0.000 | -0.592 | 0.592 |
| Hip Internal rotation | 42.10 | 22.14 | 36.85 | 22.24 | 0.485 | 0.278 | -0.375 | 0.747 |
| Ankle Dorsiflexion | 76.27 | 20.53 | 80.59 | 23.65 | 0.310 | 0.389 | -0.797 | 0.263 |
| Ankle Inversion | 8.52 | 39.01 | -1.02 | 31.39 | 0.589 | 0.222 | -0.425 | 0.719 |
| Ankle Abduction | 22.16 | 126.20 | 12.44 | 123.30 | 0.394 | 0.333 | -0.322 | 0.773 |

* denotes statistical significance ($p<0.05$); CI – Confidence Interval.

Table 4.15 representing the lower limb kinematics for the left leg in the postero-medial direction, shows no statistically significant results when comparing injured to non-injured groups. All the lower limb kinematics have little effect sizes except hip flexion angles which have a fair strength effect size (biserial rank *r*=0.5). The range for knee flexion (45.97°), hip flexion (34.95°) and ankle abduction (123.3°) are all quite large in the non-injured group.

Table 4. 16 Kinematic angles description for postero-lateral direction comparing injured and non-injured participants for left leg (n=11) (non-parametric)

| Left | Injured | | Non-Injured | | | Rank biserial correlation CI | | |
|---|---|---|---|---|---|---|---|---|
| Postero- lateral | Median (°) | Range (°) | Median (°) | Range (°) | P Value | Effect size *(r)* | Lower | Upper |
| Knee Flexion | 42.35 | 33.36 | 40.47 | 47.84 | 0.792 | 0.133 | -0.524 | 0.691 |
| Knee Abduction | -0.001 | 0.001 | 0.001 | 0.23 | 0.714 | 0.222 | -0.789 | 0.549 |
| Knee Internal Rotation | -0.001 | 0.001 | 12.22 | 20.92 | 0.257 | 0.500 | -0.866 | 0.213 |
| Hip Flexion | -13.99 | 24.87 | -23.44 | 8.98 | 0.247 | 0.467 | -0.207 | 0.840 |
| Hip Abduction | 10.15 | 32.16 | 4.73 | 36.22 | 0.082 | 0.667 | 0.089 | 0.909 |
| Hip Internal rotation | 18.56 | 14.31 | 12.22 | 20.92 | 0.167 | 0.667 | -0.039 | 0.929 |
| Ankle Dorsiflexion | 76.67 | 31.75 | 75.40 | 27.02 | 0.792 | 0.133 | -0.524 | 0.691 |
| Ankle Inversion | 0.52 | 20.34 | 2.71 | 27.54 | 0.537 | 0.267 | -0.757 | 0.416 |
| Ankle Abduction | 17.30 | 14.94 | 5.24 | 18.46 | 0.250 | 0.600 | -0.181 | 0.917 |

* denotes statistical significance ($p<0.05$); CI – Confidence Interval.

Table 4.16 shows no statistically significant differences between injured and non-injured participants for the left leg in the postero-lateral direction. Hip abduction angles (*r*=0.6) and hip external rotation (*r*=0.6) have moderate strength effect sizes. Knee flexion range for both injured (33.36°) and non-injured (47.84°) participants are large as well as hip abduction ranges (injured=32.16°; non-injured=36.2°) and ankle dorsiflexion ranges (injured=31.75°;non-injured=27.02°).

### 4.7.2 Regression model for kinematic angles

A binary logistic regression with a forward method was also performed. Only two models are generated due to multi-collinearity of the independent variable. Both of the models are statistically significant. Statistical significance is tested as indicated by the Chi square model (Df=1, n=23) (Model 1 = 6.946, p=0.008; Model 2= 16.990, p=0.000). Model 1 and 2 accounts for 24% and 49% of the variation in injury status respectively according to the Cox and Snell R square. Furthermore, Model 1 accounts for 32.4% while model 2 accounts for 65.8% of the variation in injury status according to the Nagelkerke R Square test. However, the angles of model two are very small and clinically impossible to test. Model 1 shows acceptable goodness of fit, as illustrated by the non-significant Hosmer and Lemeshow test statistics (p=0.76). The overall accuracy in classification rate shows model 1 accurately predicts 76%.

Table 4. 17 Prediction model for kinematic classification for hip, knee and ankle angles comparing injured and non-injured participants

| | B | S.E. | Wald | df | Sig. | OR | 95% C.I.for | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Ant Hip flex | -0.095 | 0.043 | 4.728 | 1 | 0.03 | 0.91 | 0.835 | 0.991 |
| Constant | -1.46 | 0.872 | 2.799 | 1 | 0.094 | 0.232 | | |

B – constant; S.E. – standard error; df – degrees of freedom; Sig – statistical significance;
OR – odds ratio; C.I. – confidence interval

As the model illustrates, an increase in the hip flexion angle in the anterior direction is associated with membership of the ‘injured group’.

| Observed | | | Predicted | | |
|---|---|---|---|---|---|
| | | | Injured | Non-injured | Percentage correct |
| Ant hip flexion | Group - Injured vs Non injured | Injured | 8 | 4 | 66.7 |
| | | Non injured | 2 | 11 | 84.6 |
| | Overall Percentage | | | | **76.0** |

Table 4.17 shows hip flexion angles in the anterior direction accurately predicts 76% of the outcomes (injured or non-injured) i.e. an increase in the anterior hip flexion angles are associated with the likelihood of being classified as “injured”.

# Chapter 5: Discussion

## 5.1 Introduction

This chapter will discuss the results and findings from this study. It will include the following topics: The reliability of the SEBT; the injury epidemiology throughout the study; the results; as well as the sensitivity and specificity of the SEBT; and findings from the 3D kinematic analysis performed.

## 5.2 Reliability of the Star Excursion Balance Test

The pilot study proved the SEBT to have both an excellent intra- and inter-rater reliability. The inter-rater reliability was tested by correlating both researchers’ recorded reach distance in each direction and was found to be between 0.99 and 1. The intra-rater reliability was tested by recording the reach distance of all three directions during the four attempts completed by the participant, the three trials and

the fourth final recorded score. There was an excellent correlation ranging from 0.85 to 0.98. This was in accordance with a previous study by Plisky et al, (2006) which reported the intra-rater reliability to be 0.89-0.93 and Gribble et al, (2013) which reported inter-rater reliability to be 0.88 to 0.92 for the three reach directions.

Gribble et al, (2013), found the ability of the rater to measure leg length adequately contributed to the reliability of the SEBT. The technique used to measure leg length in this study was the same technique used in Gribble et al, (2013) which reported large reliability scores. The leg length was measured from the ASIS to the ipsilateral medial malleolus (Gribble et al, 2013).

Furthermore, by completing three trials before the fourth recorded trial, Munro et al, (2010) showed the learning effect was no longer a contributing factor and the results remain fairly consistent resulting in strong inter-rater reliability scores. Thus this study followed the four trial protocol.

There has been no study to our knowledge that has assessed reliability as a result of verbal and/or visual instructions. However, all the studies that have reported excellent reliability scores made it clear in their protocols, the instructions were simple and consistent and a visual demonstration of the SEBT was given to each participant (Stiffler, et al 2017, Gribble et al, 2013, Hubbard, et al 2007). This leads to the assumption that clear, concise and consistent instruction, as well as a clear demonstration of the requirements of the SEBT, leads to stronger reliability scores.

### 5.3 Injury definition

For the purpose of this study, the following definition was used: an injury was defined as any musculoskeletal condition that occurred during practice or a match, which caused the player to either quit that activity or miss at least the next game or practice session. The definition for injury in this study was based on the internationally recognised injury consensus statement for cricket published by Orchard et al, (2016) and modified for the purpose of this study.

The definition of injury was modified as it needed to be broad enough to include all possible injuries to the musculoskeletal system, in any region of the body, regardless of the mechanism of injury, as to consider all of the sport-specific demands placed upon cricketers in order for the injury surveillance to be successful and at the same

time exclude causes of time missed in practice or at games due to non-musculoskeletal injuries such as illness.

The focus of this study was only on the lower quarter i.e. lower limb and lumbar spine injuries. Research in South Africa and internationally reported the highest incidence of injury sustained in cricket is in the lower limb and injuries with the highest prevalence are lumbar injuries (Stretch & Raffan 2011; Orchard et al, 2016; Frost & Chalmers, 2012). The focus was therefore, to see if the SEBT and 3D kinematic angles of the hip, knee and ankle were predictive of lower quarter injuries in cricket.

The definition used in this paper is inclusive of both contact and non-contact injuries. Although cricket generally considered as a non-contact sport the main external cause of injury reported in a study by Walker et al, (2010) was exposure to inanimate mechanical forces which included being struck by a ball or a bat. Fewer injuries were reported due to collision with other players i.e. animate forces (Walker et al, 2010). However, cricket associations strongly recommend and in some cases, enforce the use of protective personal equipment such as helmets with faceguards, pads and gloves (Walker et al, 2010). This has resulted in a decrease in the number of contact injuries and the majority of cricket injuries now reported are non-contact in nature (Orchard et al, 2016). In this study there were no contact injuries reported.

### 5.4 Injury epidemiology

One of the aims of this study was to establish if the SEBT reach distances and 3D kinematic angles were predictive of lower limb injury in cricket players. In order to establish the relationship between the reach distances, 3D kinematic angles and lower limb injury, injury surveillance was necessary. Not only did it provide epidemiological information, it also provided the basis and direction of injury prevention strategy (Junge & Dvorak, 2015).

There was however a

This study found 50% of participants sustained non-impact injuries over the 2015/2016 cricket season. On average each participant sustained 1.55 injuries. This was lower than the results of a South African study by Stretch, Raffan and Allan (2009) that found an average of 2.05 injuries per participant during the 2004/2005

and 2005/2006 provincial cricket seasons of which only 12% was due to impact. This may be due to Stretch, Raffan and Allan (2009) study was conducted over two seasons whereas this study was conducted over one. Over the two season 2004/2005 and 2005/2006 Stretch, Raffan and Allan (2009) reported fitness and practice exposure times changed among the teams from one season to the next. Even though Stretch, Raffan and Allan, (2009) reported a decrease in the incidence of injury from one season to the next, possibly due to changes in exposure times, the mean injuries per participant would have taken into account both seasons and as a result appears to be higher than the incidence reported in our study . This study was used as a comparison as it was similar in terms of the sample. Both studies used provincial cricket teams therefore; they had similar level of play on similar grounds across the country and in similar weather conditions.

Both of the South African studies, this study as well as the study conducted by Stretch and Raffan, (2011) reported higher injury rates than a study published in Australia by Orchard et al, (2016) which saw 0.61 injuries per participant for the 2015/2016 season. Stretch and Raffan, (2011) explain this is due South African cricketers being exposed to more match time when compared to Australia. The participants in this research study trained on an average of 4.8 sessions per week and played 1.8 competitive games per week. The domestic teams in South Africa played in three different tournaments concurrently in the 2015/2016 cricket season. The longest ran was the four day Sun Foil series which ran from October to February, the Ram Slam T20 challenge that ran from November to mid-December and the Momentum One Day Cup which games ran in October in 2015 (SACA, 2017).

Most participants played in all three tournaments. Using the designated player exposure hours per type of domestic cricket matches in Australia as a reference, the exposure of these cricket players was calculated (Orchard et al, 2010). On average these cricket players were exposed to 2322 hours of match time. This is not taking into account any additional workload from provincial or university tournaments such as the Varsity Cup or USSA games. The participants in Stretch, Raffan and Allan (2009) had a mean match exposure time of 2096 hours for the 2004/2005 season and 2136 hours for the 2005/2006 domestic cricket season.

Hulin et al, (2014) suggested high workloads are a significant risk for injury. The

research conducted in this study reported the incidence of injury in the lower limb was as high as 59%. The rate was much higher than the 41.6% lower limb incidence rate reported by Stretch, Raffan and Allan (2009). This may be due to Stretch, Raffan and Allan, (2009) study assessed the 2004/2005 and 2005/2006 cricket seasons. The T20 era began in 2006 and has gradually increased since, along with it injury incidence, particularly muscles strains, have also increased (Orchard et al, 2015). This may also explain the higher percentage of soft tissue injuries sustained in this study (60%) as compared to Stretch, Raffan and Allan, (2009) (42%). As explained in Chapter 2, more runs need to be made quicker due to limited number of overs thus sprinting efforts are largest in T20 matches. Yu et al, (2008) attributed eccentric contraction during the late stance phase as a characteristic of sprinting as well as injury risk. This may explain the high incidence of lower limb injuries found in this study.

In this study however, the most time missed due to injury was as a result of lumbar injuries The mean time missed from playing cricket was eleven weeks. This is in accordance with studies in Australia and New Zealand during the T20 era, that showed lumbar injuries to be the most prevalent injury thus causing the most time missed (Orchard et al, 2016, Frost and Chalmers, 2012). All the lumbar injuries in this study were sustained by fast bowlers. Ferdinands, Kersting and Marshall (2009) conducted a study on the 3D lumbar segment kinetics during fast bowling on elite level cricketers in New Zealand and reported during the delivery and follow through phase the lumbar spine flexors generate a large load at a high angular velocity possibly towards the end of available flexion range together with left lateral bending during the follow through phase promotes lumbar injury This together with high workloads, have resulted in fast bowler injury prevalence rates to be comparable to other full contact sports such as rugby and Australian football (Orchard et al, 2002; Brooks et al, 2005).

Thus preventing injuries is an important task and crucial for athletes health and wellbeing (Junge et al, 2008). One aspect of this study addressed this issue by researching the SEBT and kinematic hip, knee and ankle angles ability to predict lower limb injuries.

### 5.5 Star Excursion Balance Test reach distances

The dominant and non-dominant limb mean normalised reach distances were the highest in the anterior direction. The mean was 105.3 % compared to postero-medial and postero-lateral directions with a mean of 87.3% and 87.8%, respectively. This was in accordance with the Coughlan et al, (2012) study of healthy participants that found the anterior reach distance was greater than postero-medial and postero-lateral directions. Coughlan et al, (2012) suggested the ability to see the reach distance in the anterior direction compared to the postero-medial and postero-lateral directions, provides visual feedback resulting in less inhibition and further reach distances in the anterior direction. In contrast, a study conducted by O'Connor and Kuo, (2009) looking at direction-dependent control of balance during walking and tandem standing in healthy participants, reported anterior/posterior motion has little dependence on vision. Instead, it explains that there is the passive dynamic stability in the anterior and posterior direction of movement i.e. the CNS actively balances the head, trunk and legs on the ground with corrective torques, in an inverted pendulum. In the medial and lateral direction however, this dynamically stable body position changes. As a result, movement shows higher degrees of instability and requires more sensitivity, measured through changes in centre of pressure, and more integrative control for foot placement movement in these directions. In turn, this affects step length (O'connor & Kuo, 2009). Although our study looked at balance in the anterior, postero-medial and postero-lateral directions, the inverted pendulum shape, described as passive dynamic stability, will still change in the postero-medial and postero-lateral direction of movement.

#### 5.5.1 Star Excursion Balance Test and injury

This study found no statistically significant difference when comparing reach distances between injured and non-injured participants for the dominant and non-dominant limb. This is in contrast to research conducted by Stiffler et al, (2017) which found the SEBT reach distance in the anterior direction to be significantly lower in participants who sustained lower limb non-contact knee and ankle injuries, as compared to the healthy group. The population Stiffler et al, (2017) studied was similar to this study as both studies participants were first team athletes around collage attending ages however, Izquierdo et al, 2002 suggests different training backgrounds may play a role in functional adaptation. Similar results were found by

Plisky et al, (2006) who reported a 94% composite score difference significantly increased injury risk in high school basketball players. In this study the composite mean scores for the injured group and the non-injured group for dominant limb were very similar with 94.5% and 94.24%, respectively. However, for the non-dominant limbs the composite reach distance differences was 93.5%. Plisky et al, (2006) stated that this risk factor was more significant for girls than boys. This study only looked at male cricket players and therefore, could explain why the reach distance difference was not as large.

Other researchers have also proved the SEBT to be sensitive enough to detect lower limb injuries (Herrington et al, 2009; Hertel et al, 2006). The research showed participants with an ACL deficient limb, particularly in the anterior and postero-medial direction, and patients with chronic ankle instability in the postero-medial direction had decreased reach distances compared to healthy participants (Herrington et al., 2009; Hertel et al, 2006).

The differences in reach directions were not statistically significant however, the effect size for the non-dominant limb, when comparing the injured and non-injured participants in the postero-medial direction, was between medium to large at (biserial rank r=0.6) and just below medium for the composite score at (biserial rank r=0.4). For the dominant limb, the effect size for the anterior dominant was medium to good (Cohen's *d*=0.7), and for the postero-medial and postero-lateral were good (Cohen's *d*=0.8), indicating that the sample size was too small to statistically recognise differences and may be restricting significant findings, thus, possibly producing a false negative (Banerjee, Chitnis, Jadhav,Chaudhury, 2009). This means a correlation will test as non-significant due to a small sample size when in fact the correlation may be significant in the population, and would have tested as significant, had the sample size been larger. This is known as a type || error (Knudson & Lindsey, 2014). The effect size is valuable as the difference in reach distances may be clinically significant although not statistically significant.

Although neither of the results were statistically significant, interestingly, the difference between the dominant and non- dominant limbs in the injured participants was 1.7cm (anterior) with a small to medium effect size(Cohen's d= 0.4), 3cm (postero-medial) with a small effect size (Cohen's d= 0.2) and 3.1cm (postero-lateral) with a little to no effect size (Cohen's d= 0.1). Yet when comparing the non-injured

participants' reach direction asymmetry, the anterior direction (3.8cm) had a small to medium effect size (Cohen's d= 0.3) and postero-medial direction (6.2cm) with a medium to large effect size (Cohen's d= 0.6) were both larger than the asymmetry between dominant and non-dominant limb for the injured participants whereas the postero-lateral direction dominant non-dominant limb asymmetry was smaller (2.8cm) than the injured participants and had a small effect size (Cohen's d= 0.2). The poster-medial direction for the non-injured participants dominant compared to non-dominant limb is contradictory to Plisky et al, (2006) research, which showed a difference of 4cm or more between limbs was significantly associated with lower limb injuries. Although the results were not statistically significant the effect size was medium to high and therefore, may have been subjected to type II error. The results may have been statistically significant had the sample size been larger and may be clinically significant.

Stiffler et al, (2017) conducted similar research on a college athletic population and reported only the anterior reach direction asymmetry between dominant and non-dominant limbs to be significantly associated with lower limb knee and ankle injuries. Furthermore, the difference in reach direction for the dominant and non-dominant limb in the anterior direction for injured participants was far lower at 1.8cm (Stiffler et al, 2017). Stiffler et al (2017) research suggested applying the dominant/non-dominant reach direction difference threshold risk to 4cm, as recommended by Plisky et al (2006), would result in only 48% of the injured participants in the athletic population to have been screened correctly and therefore, suggested injury risk thresholds and cut off scores to be utilised in the sport the population it was developed for. Our study investigated cricket players whereas Plisky et al, (2006) screened basketball players and this may account for the conflicting results.

Despite conflicting reports of reach direction differences between limb thresholds, both of these studies (Plisky et al, 2006; Stiffler et al, 2017) as well as numerous other studies (Gribble et al, 2012; Herrington et al, 2009; Hertel, et al, 2002) have proved the SEBT to have strong reliability scores. Furthermore, the entire process of the SEBT was quick to set up and administer hence, findings' of our study was in accordance with a study by Gribble et al (2012) that found the SEBT a quick, easy to administer and reliable screening tool.

### 5.6 Receiver Operating Curve

The validity of the SEBT was measured by analysing the sensitivity and specificity using the ROC. The AUC is considered an effective measure of inherent validity by graphically displaying the inverse relationship between sensitivity and 1 minus specificity (false positive) (Indrayan and Kumar, 2011). Ideally a test should be both sensitive and specific and have a zero possibility of a false positive.

Sensitivity during the SEBT refers to the ability of the test to identify the participants who were injured. One minus specificity refers to the ability of the SEBT to identify participants who were at risk of injury but did not sustain an injury. Specificity is the ability of the SEBT to identify non-injured participants who are not at risk of injury. This would be represented on the ROC as the maximum area under the curve is equal to one (Hajian-Tilaki, 2013). An area under the curve equal to 0.5 is considered a chance level tool and an AUC closer to 0 is considered to be a poor tool (Hajian-Tilaki, 2013). In terms of the SEBT, the AUC will illustrate the ability of the SEBT to discriminate between injured and non-injured participants (Stiffler, et al 2017).

The ROC for the SEBT in this study, showed less accurate ratings (AUC= 0.55) for the anterior reach direction for the dominant limb and the postero-medial (AUC=0.68) and postero-lateral direction (AUC=0.61) for the non-dominant limb (AUC=0.6). Plisky et al, (2006) and Stiffler et al, (2017) studies showed the anterior reach distance to be a good indicator of lower limb injury. As previously discussed, according to Plisky et al, (2006) when the reach difference between the dominant and non-dominant limbs is equal to or greater than 4cm, the risk of injury was two and a half times more likely, and when the composite score difference was 94%, the likelihood of the participant sustaining an injury increased six-fold. Stiffler et al, (2017) showed an asymmetry of 1.8cm between the dominant and non-dominant limb to be predictive of lower limb injury. The anterior reach direction may be important for bowlers, as they are required to sprint during run up and during the delivery phase of bowling, towards the batsman in an anterior direction; also important for batsmen, as they are required to sprint between the wickets to score runs (Petersen et al, 2014; Robert et al, 2014).

In terms of the SEBT it is better for the test to have higher sensitivity and compromise on specificity as it is a screening tool. When the opposite is found (higher specificity and lower sensitivity), it will show more cricketers not to be at risk of injury when in

fact they may be. A test with higher sensitivity will incorrectly identify cricketers to be at risk of injury. For example, with a cut off score of 79% normalised reach distance in the postero-medial direction, the test has a high sensitivity, which means the test would accurately identify 81.8% of participants, with a normalised score difference in the postero-medial direction of 79% or more, as at risk of sustaining an injury. However, the 54.5% of participants identified as at risk of injury will not sustain an injury (false positive) as the specificity is relatively low. If the cut off score for the same test was chosen based on a higher specificity and lower sensitivity at 98% normalised reach distance, then only 18.2% of participants would be incorrectly identified as at risk of injury. Due to a lower sensitivity, only 36% of participants with a normalised score difference in the postero-medial direction of 98% or more, will be accurately identified as at risk of sustaining an injury. It will be beneficial for the team if more cricketers are included in injury prevention programmes than to have more injured players.

The SEBT in this study was unable to predict injury in cricket players. This was largely due to type II errors as a result of an inadequate sample size. There was however, a medium to large effect size for the non-dominant limb in the postero-medial direction and the composite scores and for the dominant limb the effect size was a medium to large and large in all three the anterior, postero-medial and postero-lateral direction.

### 5.7 Kinematics angles

#### 5.7.1 Kinematic analysis of the SEBT

Analysis of the SEBT using 3D kinematic data, and comparing the utilised joint ranges to normative values of joint ranges of motion, showed hip flexion, followed by knee flexion, to have the largest range of motion utilised in order to achieve maximum reach distance during all three reach directions; anterior, postero-medial and postero-lateral. The normative values were obtained from a reference values and database study of healthy participants by Soucie et al, (2011).

These results are similar to a finding by Robinson and Gribble, (2008) which showed the hip contributes 88.6% to 94.5% of the variance in angular displacement in postero-medial and postero-lateral direction. In the anterior direction the hip together

with knee flexion makes up 78%. However, Robinson and Gribble, (2008) examined angular displacement through a stepwise multiple regression model and all eight directions of the original SEBT was analysed for all three planes of motion at the hip and only the sagittal plane of motion for the knee. Hoch et al, (2011) added that the remaining angular displacement variance in the anterior direction is due to ankle dorsiflexion of the stance leg.

In this paper, knee flexion angles were the greatest in the postero-lateral direction and smallest in the anterior direction for both limbs. This was contradictory to previous research reported in a systematic review by Gribble et al, (2012). The systematic review reported the least amount of knee flexion occurs in the lateral direction and the greatest amount of angular displacement occurred in the anterior direction. The conflicting results may be due to the different methods of statistical analyses used in the studies reviewed by Gribble et al, (2012). These were similar to the analysis performed by Robinson and Gribble, (2008) and in comparison, to the analysis used in this paper. These studies calculated the normalised reach distances as well as hip flexion, knee flexion and ankle dorsiflexion of the injured limb and matched it to the non-injured limb and used these results in a regression model. This paper used normative reference values and compared these to the amount of range used by each of the hip, knee and ankle joint ranges in the three planes of motion i.e. sagittal, frontal and transverse planes. Furthermore Robinson and Gribble, (2008) sample size was 20 participants whereas this study could only utilise the data of 13 participants for the right limb and 11 for the left limb.

### 5.7.2 Kinematics and Injury

Analysing the available data from the 6 of the 11 injured participants a regression model showed statistically significant results for hip flexion angles as a predictor of lower limb injury. The results show decreased hip flexion in the anterior direction alone, accurately predicts 76% of the likelihood of injury, and together with increased knee external rotation angles, accurately predicts 80% of the outcome i.e. injured or non- injured.

The knee external rotation angle by itself was not statistically significant, and the angles were very small and therefore, it is not clinically useful in the prediction of lower limb injury. The difference in angles between injured and non-injured

participants would only be detected by 3D kinematic analysis. Hip flexion range of motion, on the other hand, was large enough to measure clinically with a goniometer or inclinometer. The hip flexion range of the injured participants in the anterior direction for the left leg was 11.3° less than the range of hip flexion for non-injured participants, with moderate to strong effect size (biserial rank r= 0.6). On the right leg the hip flexion range of motion in the anterior direction was 17.84° less in the injured participants than the non-injured participants, with a moderate effect size (biserial rank r= 0.57)

The regression model supports the findings of larger hip flexion angles used in the non-injured group, compared to the injured group, when reaching maximally in the anterior direction. This suggests participants with smaller hip flexion ranges in the anterior direction when comparing the two limbs, and when comparing injured to non-injured participants, may be at risk of a lower limb injury. According to a systematic review by Gribble et al, (2012) lower limb pathologies and injuries have been associated with decreased hip angles in the anterior direction. Gribble et al, (2004) reported participants with chronic ankle instability used less hip flexion than healthy participants. The hip flexion on the non-injured limb was greater than on the limb with chronic ankle instability.

Gribble et al, 2004 suggests this may be due to disruptions in one or more joints in the kinetic chain resulting in compensatory movements in the rest of the musculoskeletal system and in altered movement patterns. This allows the participant to complete the task, however, the mechanisms used to reach maximally in the anterior direction are altered and may be less efficient, subjecting the participant to an increased risk of injury (Gribble et al, 2004). When reaching maximally in the anterior direction, a decreased hip flexion range may indicate the recruitment of altered and sub-optimal movement patterns during anterior directional movements, such as running between wickets; during the run up when bowling; or running towards a ball; and therefore, increase the cricket player's risk of injury.

The regression model showed no other predictive angles for injury, however, differences in joint angles in the anterior reach direction, that are statistically significant through a rank biserial correlation, were the ankle abduction angles for both the right and left leg. It also presented with statistically significant differences between injured and non-injured participants in the postero-lateral direction on the

right leg. The difference between the ankle abduction angles of the injured and non-injured limbs was 8.2° for the anterior direction on the right limb, 8.6° for the anterior direction on the left limb and 10.5° for the postero-lateral direction on the left limb.

According to Hertel (2002), rear foot motion rarely occurs in isolation due to position of the ankle joint bones. Couple rear foot motion is called pronation and supination. (Hertel, 2002). Pronation consists of dorsiflexion, abduction and eversion (Hertel, 2002). A literature review of ACL injuries in soccer players by Geli, et al (2009) reported pronation of the ankle increases the internal rotation and abduction of the knee, increasing the risk of knee injury. Boden et al, (2009) suggested, in a study conducted on injuries in male and female sportsmen, altered ankle kinematics may lead to abnormal absorption of the ground reaction forces, placing more load in the knee and hip and increasing the risk of lower limb injury. Furthermore, Donovan and Feger (2017) suggested once the foot makes contact with the ground, and is in a closed kinematic chain, the ability to modulate response to prevent injury is diminished. The literature therefore, supports this study's findings that differences in ankle abduction angles are strongly associated and are a strong indicator of injury risk.

Knee abduction angles were too small to accurately clinically predict a lower limb injury, nonetheless, the differences between the knee abduction angles in the postero-medial direction for left leg were statistically significant when comparing injured and non-injured participants. Boden et al, (2009) analysed videos of ACL injuries in both males and females from a variety of sport, and found knee abduction angles were greater in injured participants than in non-injured participants for both males and females. Boden et al, (2009) stated during the initial movement i.e. the first two frames of the analysis, there was minimal difference between the knee abduction angles when comparing injured and non-injured participants. However, the angle difference increased from the third frame and by the fifth frame the angle difference was more than 20°. This could explain why there was no statistical difference in knee abduction in the anterior direction as the participants all began the SEBT with the anterior direction followed by postero-medial then postero-lateral. There was no statistical difference with the analysis of the left leg in the postero-medial direction.

## 5.8 Conclusion

This discussion concludes that despite cricket being considered a low to moderate injury risk game, the injury prevalence rates are high and are rising annually. Injury prevention has, as a result, become a focus and is absolutely essential. Although the SEBT statistical tests in this study were not significant, it still provided useful information regarding neuromuscular dysfunction in at risk cricket players. Effect sizes the non- dominant group postero-medial direction was medium to good and for the composite score was good. For the dominant limb the effect size was medium to good in the anterior direction and good for the poster-medial and poster-lateral direction. This suggests the sample size was too small and is restricting statistically significant findings. The 3D kinematic analysis of the hip, knee and ankle angles provided useful information regarding the source of the poor performance of kinematic strategies. In particular, hip flexion in the anterior direction, knee abduction in the postero-medial direction and ankle abduction in the postero-lateral and anterior direction, were strongly associated with injury.

## Chapter 6: Conclusion

### 6.1 Conclusion relating to objectives

The objectives of this study were as follows:

To establish the ability of the SEBT reach distances to predict injury in cricket players.

Although the SEBT reach distances were not statistically significant when comparing the difference in reach direction between injured and non-injured participants; the effect sizes for all three reach directions; as well as the composite score on the dominant limb and in the anterior direction on the non-dominant limb; were medium to large, indicating the small sample size to be susceptible to type II error. With a larger sample size the results may have been statistically significant as indicated by the reported effect size and may therefore, be clinically significant. The SEBT provided useful information regarding limb asymmetry and, together with joint angle analysis in the anterior, postero-medial and postero-lateral direction, may be a useful tool in identifying at risk cricket players. Differences in reach distances between dominant and non-dominant limbs have been shown in literature to have a strong association to injury.

To describe the contribution of lower limb kinematic hip, knee and ankle angles, during execution of the SEBT.

The kinematics of the hip, knee and ankle angles were described and were in line with previous literature, which concluded, hip flexion angles are the main contributor of movement during the execution in all three directions of the SEBT.

To establish the relationship between the kinematic hip, knee and ankle angles, and injury.

This study showed the hip flexion angles in the anterior direction can be used to predict injury in cricket players. Furthermore, differences between ankle abduction angles and knee abduction angles in the postero-lateral and postero-medial directions, respectively, and ankle abduction angles on the left leg when comparing

injured and non-injured participants were statistically significant when comparing injured to non-injured participants.

This study emphasised the growing incidence and prevalence of injuries reported in cricket. The SEBT was shown to be a quick and reliable screening tool that mimics the neuromuscular demands of sport and is, therefore, useful to predict lower limb injury in cricket players. The 3D kinematic hip, knee and ankle data supplemented findings from the SEBT and provided useful information as to the source of poor SEBT performance, and thus, can be used in the direction of injury risk management.

### 6.2. Limitations

Although the sample size was calculated prior to the commencement of the study using data from similar studies, the sample size still seems to be susceptible to type II error and may be incorrectly rejecting the alternative hypothesis in terms of the SEBT. The sample size was also significantly affected during the analyses of the 3D kinematics angles of the hip, knee and ankle due to missing markers during the trajectory of movement therefore, only 13 of the 22 participants' right limb data and 11 left limb data and 6 of the 11 injured participants data was available for analysis.

The pre-season (Appendix A) and weekly questionnaire (Appendix B) were assessed for content validity prior to the study, however, in retrospect both of these forms lacked clarity and specificity in the questions. With reagrds to the pre-season questionnaire, the research began during the pre-season when participants had not participated in competitive games as yet and the information of previous injuries had no time period given on the form. Despite the lack of clarity the participants provided sufficient information as the pre-season form was filled out in the presence of the researcher. The above two questions did arise and were clarified verbally. The question of frequency of competitive games and the previous injuries were both in reference to the previous season.

In terms of the weekly questionnaire, both the region and tissue injured should be specified on the form. Furthermore, in retrospect the workload data should also be added to the form. During this study the coaches provided the information, with the participants consent, on the number of training sessions and competitive games which took place per week and if any of the participants had missed either. This

sample of cricket players were participants in other observational and injury surveillance studies during the cricket season under review which may explain why this shortcoming of the form was not highlighted during the pilot study and during the main study as the participants answered the questions very specifically.

Other limitations of this research related to the 3D kinematics component. The 3D kinematic analysis was captured using the Optitrack software and cameras which are expensive and, therefore, not easily accessible to all sports teams. Cheaper alternatives have been researched but were not included in this dissertation.

Furthermore, kinematic movement analysis is that the markers are placed on the skin. Markers move or fall off during testing & present a common challenge when using a passive marker system. Skin movement cannot be controlled, and this is a problem for all biomechanical studies using optical motion analysis systems with passive markers.

### 6.3 Future recommendations

This study should be repeated with a larger sample size to reduce type II errors. Furthermore, to improve accuracy of data captured through the 3D kinematic system, the pilot study in future should to assess the ability of the camera positions to pick up the necessary markers in the analysis programmes and adjustments can then be made prior to the commencement of the main study.

A recommendation for future research will be to add EMG to future studies to establish the muscular relationship to the SEBT, 3D hip, knee and ankle kinematics, and injury, as well as to assess performance, to see if there is a relationship between specific kinematics, muscle activation, balance scores and performance.

Lastly, this study will be beneficial if it is repeated using a more easily accessible, cheaper method of kinematic analysis such as the Mark Nintendo WII to see if it is as useful, valid and reliable as the Opitrack system.

### 6.4 Clinical recommendations

It is recommended that the SEBT be used in conjunction with movement analysis in order to provide greater insight into the risk factors of injury. Special attention should

be given to known risk factors such as hip flexion, as well as, ankle and knee abduction angles for participants that demonstrate poor performance of the SEBT. Cricket players can then be rehabilitated specifically according to findings of the SEBT together with the movement analysis data in order to reduce the risk of injury in season.

## REFERENCE LIST


1. Akseki, D., Akkaya, G., Erduran, M. & Pinar, H. 2008. Proprioception of the knee joint in patellarfemoral pain syndrome. Acta Orthopaedica et Tramatologica Turcica. 42(5): 316-321
2. Aminaka, N. & Gribble, P.A. 2008. Patella taping, patellofemoral pain syndrome, lower extremity kinematics, and dynamic postural-control. Journal of Athletic Training. 43(1):21-28.
3. Barwick, A., Smith, H. & Chuter, V., 2012. The relationship between foot motion and lumbopelvic-hip function: a review of the literature. The Foot, 22,(3); 224-231
4. Boden, P., Torg, J.S., Knowles, S.B. & Hewett, T. 2009. Video Analysis of Anterior Cruciate Ligament Injury. Abnormalities in Hip and Ankle Kinematics. American Journal of Sports Medicine. 37(2): 252-259
5. Bradley, P.S. & Portas, M.D. 2007.The relationship between preseason range of motion and muscle strain injury in elite soccer players. Journal of Strength and Conditioning Research. 21;1155-1159
6. Brooks, J.H., Fuller, C.W., Kemp, S.P.T. & Reddin, D.B. 2005. Epidemiology of injuries in English professional rugby union: part 1 match injuries. British Journal of Sports Medicine. 39:757-766.
7. Chaudary, S. 2009. Hypothesis testing, Type I and Type II errors. Industrial Psychiatry. 18(2): 127-131
8. Chin, A., Elliot, B., Anderson, J., Lloyd, D. & Foster. D. 2009. The off-break and "doosra": Kinematic variations of elite and sub-elite bowlers in creating ball spin in cricket bowling. Journal of Sports Biomechanics. 8(3); 187-198
9. Chuter, V.H. & Janse de Jonge, X.A. 2012. Proximal and distal contributions to lower extremity injury: A review of the literature. Gait & Posture. 36(1); 7-15
10. Clark, R.C., Saxion, C.E. & Cameron, K.L. 2010. Associations between three clinical assessment tools for postural stability. North American Journal of Sports Physical Therapy. 5(3): 122-130.
11. Clark, U., Roijezon, N. & Treleaven, J. 2015. Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Manual Therapy. 20(3): 368-377
12. Cohen, J. 1992. A power primer. Psychological Bulletin. 112(1): 155-9.

13. Coughlan, G., Fullam, K., Delahunt, E., Gissane, C. & Caulfield, B.M. 2012. A Comparison between Performance on Selected Directions of the Star Excursion Balance Test and the Y Balance Test. Journal of Athletic Training. 47(4): 366-371.
14. Dallinga, J.M., Benjaminse, A. & Lemmink, K. 2012. Which Screening Tools Can Predict Injury to the Lower Extremities in Team Sports? Sports Medicine. 42(9): 791-815
15. Davies, R.A., Du Randt, R., Venter, D. & Stretch, R.A. 2008. Cricket: nature and incidence of fast bowling injuries at an elite, junior level and associated risk factors. South African Journal of Sports Medicine. 20(4):115-118
16. Dennis, R.J., Finch, C.F., McIntosh, A.S. & Elliott, B.C. 2008. Using field-based tests to identify injury risk factors for fast bowlers in cricket. British Journal of Sports Medicine. 9: 1-20
17. Dennis, R., Farhart, P., Goumas, C. & Orchard, J. 2003. Bowling workload and the risk of injury in elite cricket fast bowlers. Journal of Science and Medicine in Sport. 6(3): 359-67.
18. Doherty, C., Bleakley, C., Hertel, J., Ryan, J., Caulfield, B. & Delahunt, E. 2014. Acute ankle sprain injury alters kinematic and centre of pressure measures of postural control during single limb stance. British Journal of Sports Medicine 48(7): 586-616
19. Donovan, L. & Feger, M.A. 2017. Relationship between ankle plane kinematic during different functional tasks. Gait and posture. 54: 214-220
20. Duhig, S., Shield, A.J., Opar, D., Gabbett, T.J., Ferguson, C. & Williams, M. 2016. Effect of high-speed running on hamstring strain injury risk. British Journal of Sports Medicine. 50(24):1536-1540
21. Eltoukhy, M., Kuenze, C., Oh, J., Wooten, S. & Signorile, J. 2017. Kinetic-based assessment of lower limb kinematics and dynamic postural control during the Star Excursion Balance Test. Gait and Posture. 58:421-427.
22. Erickson, L. & Sherry, M. 2017. Rehabilitation and return to sport after hamstring strain injury. Journal of Sport and Health Science. 6(3): 262-270
23. Engstrom, C.M., Waker, D.G., Kippers, V., Mehnert, A.J. 2007. Quadratus lumborum asymmetry and L4 pars injury in fast bowlers: A prospective MR study. Medicine and Science in Sport & Exercise. 39(6): 910-917
24. Farrokhi, S., Pollard, C.D., Souza, R.B. & Chen, Y.J. 2008. Trunk position influences the kinematics, kinetics, and muscle activity of the lead lower

extremity during the forward lunge exercise. Journal of Orthopaedic & Sports Physical Therapy. 8(7): 403-409

25. Ferdinands, R., Kersting, U. & Marshall, R.N. 2009. Three-dimensional lumbar segment kinematics of fast bowling in cricket. Journal of Biomechanics. 42(11): 1616-1621.
26. Filipa, A., Byrnes, R., Paterno, M.V., Myer, G.D. & Hewett, T.E. 2010. Neuromuscular training improves performance on the Star Excursion Balance Test in young female athletes. Journal of Orthopaedic & Sports Physical Therapy. 40(9): 551-8.
27. Fischer, K.M., Willwacher, S., Harmill, J. & Bruggerman, P. 2017. Tibial rotation in running: Does rear foot adduction matter? Gait and Posture. 51: 188-193
28. Fong, C.M., Blackburn, T., Norcross, M.F., McGrath, M. & Padua, D.A. 2011 Ankle-Dorsiflexion Range of Motion and Landing Biomechanics. Journal of Athletic Training. 46 (1): 5-10
29. Frost, W.L & Chalmers, D.J. 2012. Injury in Elite New Zealand Cricketers 2002-2008: Descriptive Epidemiology. British Journal of Sports Medicine. 1-6
30. Fullam, K., Caulfield, B., Coughlan, G. & Delahunt, E. 2014. Kinematic Analysis of Selected Reach Directions of the Star Excursion Balance Test Compared With the Y-Balance Test. Journal of Sport Rehabilitation. 23; 27-35
31. Fuller, C.W., Ekstrand, J., Junge, A., Andersen, T.E., Bahr, R., Dvorak, J., Hägglund, M., McCrory, P. & Meeuwisse, W.H. 2006. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scandinavian Journal of Medicine and Science in Sport. 16(2). 83-92
32. Fuller, C., Molloy, M., Bagate, C., Bahr, R., Brooks, J., Donson, H., Kemp, S., McCrory, P., McIntosh, A., Meeuwisse, W., Quarrie, K., Raftery, M. & Wiley, P. 2007. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. British Journal of Sports Medicine. 41(5): 328-331.
33. Gabbe, B., Finch, C.F., Wajswelner, H. & Bennell, K.L. 2004. Predictors of lower extremity injuries at the community level of Australian football. Clinical Journal of Sport Medicine. 14(2):56-63.

34. Glazier, P.S. & Wheat, J.S. 2014. An integrated approach to the biomechanics and motor control of cricket fast bowling techniques. Sports Medicine. 44(1):25-36
35. Goldman, E. & Jones, D. 2011. Interventions for preventing hamstring injuries: a systematic review. Physiotherapy Journal. 97(2) 91-99
36. Greiner, M., Pfeiffer, D. & Smith, R.D. 2000. Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. Preventive Veterinary Medicine. 45: 23-41.
37. Gribble, P.A and Hertel, J. (2003). Considerations for normalizing measures of the Star Excursion Balance Test. Measurement in Physical Education and Exercise Science. *7*(2): 89–100
38. Gribble, P.A., Hertel, J. & Plisky, P. 2012. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. Journal of Athletic Training. 47(3): 339-357.
39. Gribble, P.A, Kelly, S.E., Refshauge, K.M. & Miller, C. 2013. Inter-rater reliability of the Star Excursion Balance Test. Journal of Athletic Training. 48(5): 621-626
40. Gribble, P.A., Tucker, W.S. & White, P.A. 2007. Time-of-day influences on static and dynamic postural control. Journal of Athletic Training. 42(1): 35-41.
41. Hajian-Tilaki, K. 2013. Receiver Operating Characteristic (ROC) curve analysis for medical diagnostic test evaluation. Caspian Journal of Internal Medicine. 4(2); 627-635
42. Henderson, G., Barnes, C.A. & Portas, M.D. 2009. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. Journal of Science and Medicine in Sport.13 (4); 397-402.
43. Herrington, L., Hatcher, J., Hatcher, A. & McNicholas, M. 2009. A Comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. Knee. 16(2): 149-152
44. Hertel, J. 2002. Functional anatomy, pathomechanics and pathophysiology of lateral ankle instability. Journal of Athletic Training. 37(4) 364-375
45. Hides, J., Stanton, W., Freke, M., Wilson. S., McMahon. S., Richardson, C. 2008. MRI study of the size, symmetry and function of the trunk muscles among elite cricketers with and without back pain. British Journal of Sports Medicine. 42(10): 509-513.

46. Hoch, M.C., Staton, G.S. & McKoen, P.O. 2011. Dorsi-flexion range of motion significantly influences dynamic balance. Journal of Science and Medicine in Sport. 14(1); 90-92
47. Hubbard, T.J., Kramer, L.C., Denegar, C.R. & Hertel. J. 2007. Correlations among multiple measures of functional and mechanical instability in subjects with chronic ankle instability. Journal of Athletic Training. 42(3): 361-366.
48. Hulin, B., Gabbett, T., Blanch, P., Chapman, P., Bailey, D., & Orchard, J.W. 2014. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. British Journal of Sports Medicine. 48. 708-712.
49. Indrayan, R. & Kumar, A. 2011. Receiver Operating Curve (ROC) for medical researchers. Indian Paediatrics. 48; 277-288
50. Izquierdo, M., Hakkinen, K., Gonzalez-Badillo, J.J., Ibanez, J., & Gorostiaga, E.E. 2002. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sport. European Journal of Applied Physiology. 87; 264-271
51. Jamaluddin, S., Sulaiman, A.R., Kamarul Imran, M., Juhara, H., Ezane, M., & Nordin, S. 2011. The reliability and accuracy of the tape measurement method with a nearest reading of 5mm in the assessment of leg length discrepancy. Singapore Medical Journal. 52(9); 681-684
52. Junge, A., Engebretsen, L., Alonso, J.M. & Mountjoy, M. 2008. Injury surveillance in multi-sport events: the International Olympic Committee approach. British Journal of Sports Medicine. 42:413-21
53. Junge, A. & Dvorak, J. 2015. Football injuries during the 2014 FIFA World Cup. British Journal of Sports Medicine. 49(9); 599-602
54. Kiesel, K.B., Uhl, T., Underwood, F.B. & Nitz, A.J. 2008. Rehabilitative ultrasound measurement of select trunk muscle activation during induced pain. Manual Therapy. 13(2): 132-138
55. Kiesel, K., Plisky, P.J. & Voight, M.L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen? North American Journal of Sports Physical Therapy. 2: 147-158.
56. Knudson, D.V. & Lindsey, C. 2014. Type I and Type II errors in correlations of various sample sizes. Comprehensive Psychology. 3(1): 1-5
57. Leardini, A., Sawacha, Z., Paolini, G. & Ingrosso, S. 2007. A new anatomically based protocol for gait analysis in children. Gait and Posture. 26(4): 560-571

58. Lee, M.J., Reid, S.L., Elliott, B.C. & Lloyd, D.G. 2009. Running biomechanics and lower limb strength associated with prior hamstring injury. Medicine and Science in Sports and Exercise. 41(10):1942-51
59. Levanon, Y., Gefen, A., Lerman, Y., Givon, U. & Ratzon, N. 2010. Validity and reliability of upper extremity three-dimensional kinematics during a typing task. Gait and Posture. 32(4); 469-47
60. Lui, H., Garrett, W., Moorman, C. & Yu, B. 2012. Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature. Journal of Sport and Health Science. 1(2); 92-101
61. Macaulay, C., Osis, S., Clermont, C. & Ferber, R. 2017. The use of real-time feedback to improve kinematic marker placement consistency among novice examiners. Gait and Posture. 58; 440-445
62. MacDonald, D., Cronin, J., Mills, J., McGuigan, M. & Stretch, R. 2013. A review of cricket fielding requirements. South African Journal of Sports Medicine 25(3): 87-92
63. MacDonald, D., Cronin, J., Mills, J. & Stretch, R. 2013. Wicket-Keeping in Cricket: A Literature Review. International Journal of Sports Science and Coaching. 8(3): 531-542.
64. Mansingh, A., Harper, L., Headley, S., King-Mowatt, J. & Mansingh, G. 2006. Injuries in West Indies cricket 2003-2004. British Journal of Sports Medicine. 40; 119-23
65. McKoen, P.O. & Hertel, J. 2008. Systematic review of postural control and lateral ankle instability, Part 1: Can deficits be detected with instrumented testing? Journal of Athletic Training, 43(3): 293-304
66. McLoed, V., Armstrong, T., Miller, M. & Sauers, J. 2009. Balance improvements in female high school basketball players after a 6-week neuromuscular-training program. Journal of Sport Rehabilitation. 18; 465-481
67. Munro, A.G. & Herrington, L.C. 2010. Between-session reliability of the Star Excursion Balance Test. Physical Therapy in Sport 11(4):128-32
68. O'Connor, S.M. & Kuo, A. 2009. Direction dependent control of balance during walking and standing. Journal of Neurophysiology. 102(3): 1411-1417
69. Olivier, B., Stewart, A.V. & McKinon, W. 2014. Injury and lumbar reposition sense in cricket pace bowlers in neutral and pace bowling specific body positions. The Spine Journal. 14:1447-1453.

70. Olivier, B., Taljaard, T., Burger, E., Brukner, P., Orchard, J., Gray, J., Botha, N., Stewart, A. & Mckinon, W. 2016. Which extrinsic and intrinsic factors are associated with non-contact injuries in adult cricket fast bowlers? Journal of Sports Medicine. 46(1). 79-101
71. Olivier, B., Stewart, A.V., Olorunju, S.A.S. & McKinon, W. 2015. Static and dynamic balance ability, lumbo-pelvic movement control and injury incidence in cricket pace bowlers. Journal of Science and Medicine in Sport. 18: 19-25.
72. Olmsted L.C., Carcia, C.R., Hertel, J. & Shultz, S.J. 2002 Efficacy of the Star Excursion Balance Tests in detecting reach deficits in subjects with chronic ankle instability. Journal of Athletic Training. 37(4):501-506
73. Olmsted L.C. & Hertel, J. 2004. Influence of foot type and orthotics on static and dynamic postural-control. Journal of Sports Rehabilitation. 13(1):54-66.
74. Orchard, J., James, T., Alcott, E., Carter, S. & Farhart, P. 2002. Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. British Journal of Sports Medicine. 36:270-275
75. Orchard, J., James, T., Kountouris, T. & Portus, M. 2010. Changes to injury profile (and recommended cricket injury definitions) based on increased frequency of Twenty20 cricket matches. Journal of Sports Medicine. 1: 63-76.
76. Orchard, J., Kountouris, A. & Sims, K. 2016. Incidence and prevalence of elite male cricket injuries using updated consensus definition. Open Access Journal of Sports Medicine. 7: 187-194.
77. Orchard, J., Kountouris, A. & Sims, K. 2017. Risk factors for hamstring injuries in Australian male professional cricket players. Journal of Sport and Health Science. 6(3), 271-274
78. Orchard, J., Newman, D., Stretch, R., Frost, W., Mansingh, A. & Leipus, A. 2005. Methods for injury surveillance in International cricket. Journal of Science and Medicine in Sport. 8(1), 1-14
79. Orchard, J., Ranson, C., Olivier, B., Dhillon, M., Gray, J., Langley, B., Mansingh, A., Moore, I.S., Murphy, I., Patricios, J., Alwar, T., Clark, C.J., Harrop, B., Khan, H.I., Kountouris, A., Macphail, M., Mount, S., Mupotaringa, A., Newman, D., O'Reilly, K., Peirce, N., Saleem, S., Shackel, D., Stretch, R. & Finch, CF. 2016a. International consensus statement on injury surveillance in cricket: a 2016 update. British Journal of Sports Medicine. 50: 1245-1251

80. Orchard, J. & Thomas, M. 2002. The management of muscle stain injuries: An early return versus the risk of recurrence. Clinical ournal of Sports Medicine. 12(1), 3-5
81. Pardiwala, D.N., Rao, N.N., Varshney, A.V. 2017. Injuries in cricket. The American Orthopaedic Society for Sports Medicine. Orthopaedic and sports medicine 16(2): 1-6.
82. Parreira, R.B., Grecco, L. & Oliveira, C.L. 2017. Postural control in blind individuals: A systematic review. Gait and Posture. 57: 161-167
83. Penn, M. & Spratford, W. 2012. Are current coaching recommendations for cricket batting technique supported by biomechanical research? Journal of Sports Biomechanics. 11(3): 311-323
84. Petersen, C.J., Pyne, D.B., Dawson, B.T., Kellett, A.D. & Portus, M.R. (2011) Comparison of training and game demands of national level cricketers. Journal of Strength and Conditioning Research. 25; 1306-1311
85. Petersen, C., Pyne, D., Portu, S. & Dawson, B. 2009. Quantifying positional movement patterns in Twenty20 cricket. International Journal of Performance Analysis in Sport. 9(2); 165-170
86. Petersen, J., Pyne, D., Dawson, B., Portus, M. & Kellet, A. 2010. Movement patterns in cricket vary by both position and game format. Journal of Sports Science. 28(1), 45-52.
87. Plisky, P.J., Gorman, P.P., Butler, R.J., Kiesel, K.B., Underwood, F.B. & Elkins, B. 2009. The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. North American Journal of Sports Physical Therapy. 4(2): 92-9.
88. Plisky, P.J., Rauh, M.J., Kaminski, T.W. & Underwood, F.B. 2006. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. Journal of Orthopaedic and Sports Physical Therapy, 36(12): 911-919
89. Pohl, M.B., Lloyd, C. & Ferber, R. 2010. Can the reliability of three-dimensional running kinematics be improved using functional joint methodology? Gait and Posture. 32(4); 559-563
90. Portney, L.G. & Watkins, M.P. 2009. Foundations of clinical research: applications to practice (Third Edition ). London: Pearson Prentice Hall.

91. Portus, M., Mason, B.R., Elliott, B.C., Pfitzner, M.C. & Done, R.P. 2004. Cricket: Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. Sports Biomechanics. 3(2): 263-84.
92. Potier, T.G., Alexander, C.M. & Seynnes, O.R. 2009. Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. European Journal of Applied Physiology. 105(6): 939-944
93. Ranson, C., Burnett, A.F., King, M., Patel, N., O' Sullivan, P. 2008. Three relationship between bowling action classification and three dimensional lower limb kinematics. Journal of Sports Sciences. 23(3): 267-276.
94. Ranson, C., Hurley, R., Rugless, L., Mansingh, A. & Cole, J. 2013. International cricket injury surveillance: a report of five teams competing in the ICC Cricket World Cup 2011. British Journal of Sports Medicine. 47: 637-643.
95. Richards, J. 2008. Biomechanics in Clinic and Research. London, Churchill Livingstone.
96. Robert, G.L., Callaghan, S.J. & Jeffriess, M.D. 2014. Acceleration kinematics in cricketers: Implications for performance in the field. Journal of Sports Science and Medicine. 13(1): 128-136.
97. Robinson, R.A. & Gribble, P.A. 2008. Support for a reduction in the number of trials needed for the Star Excursion Balance Test. Archives of Physical Medicine and Rehabilitation. 89(2): 364-370
98. Roijezon, U., Clark, N. & Treleaven, J. 2015; Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Manual Therapy. 20(3); 368-377
99. Rudkin, S.T. & O'Donoghue, P.G. 2008 Time-motion analysis of first-class cricket fielding. Journal of Science and Medicine in Sport. 11: 604-607
100. Schache, A.G., Wrigley, T.V., Baker, R. & Pandy, M.G. 2009. Biomechanical response to hamstring muscle strain injury. Gait and posture. 29(2): 332-338.
101. Shanley, E., Rauh, M.J. & Michener, L.A. 2011. Incidence of injuries in high school softball and baseball players. Journal of Athletic Training. 46(6): 648-654
102. Sherry, M., Johanston, T.S. & Heiderscheit, B.C. 2015. Rehabilitation acute hamstring strain injuries. Clinical Spots Medicine. 34:263-284

103. Smith, M. & Bell, D. 2013. Negative effects on postural control after anterior cruciate ligament reconstruction as measured by the Balance Error Scoring System. Journal of Sport Rehabilitation. 22; 224-228.

104. Stiffler, M., Bell, D., Sanfilippo, J., Hetzel, A., Pickett, K & Heiderscheit, B. 2017. Star Excursion Balance Test anterior asymmetry is associated with injury status in division I collageiate athletes. Journal of Orthopaedics and Sports Physical Therapy. 47(5); 339-346

105. Sole, G., Milosavljevic, S., Nicholson, H. & Sullivan, J. 2012. Altered muscle activation following hamstring injuries. British Journal of Sports Medicine. 46:118-123.

106. Soomro, N., Sanders, R., Soomro, M. 2015. Cricket injury prediction and surveillance by mobile application technology on smartphones. Journal of Science and Medicine in Sport. 19(6): 2-32

107. Soucie, J., Wang, C., Forsyth, A., Funk, S., Denny, M., Roach, K. & Boone, D. 2011. Range of motion measurements: reference values and database for comparison studies. Haemophilia. 17(3): 500-507

108. Stretch, R.A., Raffan, R.P. & Allan, N. 2009. Injury patterns of South African provincial cricket players over two seasons. South African Journal of Sports Medicine. 21(4): 151-155

109. Stretch, R. & Raffan, R. 2011. Injury patterns of South African International cricket players over a two-season period. South African journal of sports medicine. 23(2): 45-49

110. Stretch, R.A. 2003. Cricket injuries: a longitudinal study of the nature of injuries to South African cricketers. British Journal of Sports Medicine. 37: 250-253.

111. Stuelcken, M.C., Portus M.R. & Mason B.R. 2005. Off side front foot drives in men's high performance Cricket. Journal of Sports Biomechanics. 4(1). 17-25

112. Timpka, T., Alonso, J.M., Jacobson, J., Junge, A., Branco, P., Clarsen, B., Kowalski, J., Mountjoy, M., Nilsson, S., Pluim, B., Renström, P., Rønsen, O., Steffen, K. & Edouard, P. 2014. Consensus statement on injury and illness definitions and data collection procedures on epidemiological studies in athletics (track and field). . British Journal of Sports Medicine. 48:483–490

113. Von Hagen, K., Roach, R. & Summers, B. 2000. The sliding stop: A technique of fielding in cricket with a potential for serious knee injury. British Journal of Sports Medicine. 34(5); 379-381

114. Wickington, K.L. & Lintthrone, N.P. 2017. Effects of ball weight on speed, accuracy and mechanics in cricket fast bowling. Sports. 5(1): 18-22

115. Wikstrom, E.A. Tillman, M.D., Chmielewski, T.L., Cauraugh, J.H., Naugle, K.E. & Borsa, P.A. 2010. Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. Scandinavian Journal of Medicine and Science in Sports 20: 137-144

116. Willems, T., Witvrouw, E., Verstuyft, J., Vaes, P., De Clerq, D. 2002. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. Journal of athletic Training. 37(4): 487-493

117. Winter, D.A., Patla, A.E. & Frank, J.S. 1990. Assessment of balance control in humans. Medical Progress through Technology. 16(1-2):31-51

118. Woolmer, B., Noaks, T. & Moffett, H. 2008. Bob Woolmer's art and science of cricket, London, UK: New Holland Publishing 2008. Citied in Penn & Spratford, 2012.

119. Worthington, P., King, M. & Ranson, C. 2013. The Influence of Cricket fast bowlers' front leg technique on peak ground reaction forces. Journal of Sports Science. 31(4): 434-441

120. Yu, B., Queen, R.M., Abbey, A., Liu, Y., Moorman, C.T. & Garrett, W.E. 2008. Hamstring muscle kinematics and activation during overground sprinting. Journal of Biomechanics. 41: 3121-3126

121. Zazulak, B.T., Hewett, T.E., Reeves, N.P., Goldberg, B. & Cholewicki, J. 2007. The effects of core proprioception on knee injury: A prospective biomechanical-epidemiological study, American Journal of Sports Medicine. 35(3): 368-373

Appendix A WEEKLY QUESTIONNAIRE

Instructions

A. Answer all questions below
B. Fill out in chronological order with the most recent 1st.

Study number: _____

Injury surveillance

Have you suffered an injury this week?

Injury definition: an injury that resulted in loss of at least one day of sporting activity OR that occurred during sporting activity that required medical attention (Physio, paramedics, etc)

Yes

No

If yes, please specify:

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Date of injury | | | |
| Region | | | |

Side of the injury (If applicable)

| | Injury 1 | | Injury 2 | | Injury 3 | |
|---|---|---|---|---|---|---|
| | Dominant | Non-Dominant | Dominant | Non-Dominant | Dominant | Non-Dominant |
| Left | | | | | | |
| Right | | | | | | |
| Bilateral | | | | | | |

How did the injury occur?

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Contact | | | |
| Non-contact | | | |

Briefly explain how the injury occurred:

Injury 1:

Injury 2:

Injury 3:

During which activity did the injury/injuries occur?

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Batting training | | | |
| Batting Match | | | |
| Bowling training | | | |
| Bowling match | | | |
| Fielding training | | | |
| Fielding match | | | |
| Gym | | | |
| Fitness | | | |
| Other | | | |

Management of injury/injuries:

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Surgery | | | |
| Medication | | | |
| Physiotherapy | | | |
| Strapping | | | |
| Brace | | | |
| Rest | | | |
| No treatment | | | |
| Other | | | |

If you consulted with a medical professional please specify profession and diagnosis:

Significance of injury: (Specify number of sessions missed or adjusted)

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Limitations during training | | | |
| Limitations during match | | | |
| Unable to participate in Match | | | |
| Unable to participate in training | | | |

Have you previously suffered from the same injury/injuries?

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Yes | | | |
| No | | | |
| Year of previous injury | | | |

Appendix B PRE-SEASON QUESTIONNAIRE

Instructions

A. Answer all questions below
B. Fill out in chronological order with the most recent 1st.

Study number: _____

Age:

Number of seasons playing cricket:

Highest team selection:

Playing position:

Batsman

Fielder

*Bowler

*If you are a bowler please specify which type of bowler: _____

Leg dominance when batting

Right

Left

Leg dominance when bowling

Right

Left

Leg dominance in general

Right

Left

How often do you train?

_____

How often do you participate in competitive games?

_____

Do you participate in other sports apart from cricket?

Yes

No

If yes, specify _____

In- season

Out of season

What shoes do you wear to train?

Do you wear bowling or batting shoes?

Do you wear any of the following external wear?

Yes

No

| | Region | Last time changed | |
|---|---|---|---|
| Strapping | | | |
| Brace | | | |
| Orthotics | | | |

Do you currently have any injuries?

Injury definition: an injury that resulted in loss of at least one day of sporting activity OR that occurred during sporting activity that required medical attention (Physio, paramedics, etc)

Yes

No

If yes, please specify:

| Injury 1 | Injury 2 | Injury 3 |
|---|---|---|
| | | |
| | | |

Have you suffered from previous injuries?

Yes

No

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| | | | |
| Year | | | |

Region of injury/injuries:

| Injury 1 | Injury 2 | Injury 3 |
|---|---|---|
| | | |

How did the injury occur?

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Contact | | | |
| Non-contact | | | |

Briefly explain how the injury occurred:

Injury 1:

Injury 2:

Injury 3:

Management of previous injury/injuries:

| | Injury 1 | Injury 2 | Injury 3 |
|---|---|---|---|
| Surgery | | | |
| Medication | | | |
| Physiotherapy | | | |
| Strapping | | | |

| | | | |
|---|---|---|---|
| Brace | | | |
| Rest | | | |
| No treatment | | | |
| Other | | | |

How many training sessions did you miss?

| Injury 1 | Injury 2 | Injury 3 |
|---|---|---|
| | | |

How many matches did you miss?

| Injury 1 | Injury 2 | Injury 3 |
|---|---|---|
| | | |

Appendix C DATA COLLECTION SHEET

Star Excursion Balance Test

| | Right (cm) | Left (cm) |
|---|---|---|
| Anterior | | |
| Postero-medial | | |
| Postero-lateral | | |
| Leg Length | | |

Appendix D INFORMATION DOCUMENT

Study title: The Star Excursion Balance Test, Kinematics and Injury

Good Day

Introduction:
I, Taskeen Hoosen, am doing my research in predicting injury and performance in cricket players. In this study we want to learn if a balance test called the Star Excursion Balance Test can be used for the prediction of injury and performance in cricket players. I am also researching the joint activity during this test using non-invasive joint kinematics system. This is so that I can learn more specifically what is required anatomically to perform well in this test, and as a result, prevent injury and perhaps contribute to the improvement in performance. This is significant even though cricket is generally considered to be a low risk sport, there has been a rise in incidence of injury and at least 63% of the injuries incurred resulted in match time being lost.

Invitation to participate: We are inviting you to take part in this research and will be most grateful if you are willing to participate.

Who is eligible to take part in the study?
Male cricket players participating in the 2015/2016 cricket season. Cricketers with history of any central nervous system or peripheral nervous system disorders that affect proprioception; those with a history of concussion or balance disorders in the last six months; and cricketers that are receiving proprioception/balance training, will not be eligible to take part in this study

What is involved in the study – This study is an observational study will commence in July 2015-March 2016. Testing will be done during one of your cricket practice sessions. On the day of testing, you will be asked to complete a questionnaire enquiring about demographic and injury-related information. You will be required to wear an above knee dark shorts and a white t-shirt. Your leg length will be measured

using a standard measuring tape. This is required for one of the calculations in the study. You will also have reflective markers attached to specific sites on your body using two-way tape. The areas may need to be shaven and will be cleaned with alcohol so that the markers remain attached during the test. Thereafter, you will perform the SEBT test 4 times before the final score is recorded. The test requires you to step as far forward and to either side as far as possible while maintaining your balance. You will be recorded with 12 high speed video cameras while performing the SEBT. Joint kinematics will also be recorded. The entire testing procedure should not take more than 30 minutes.

Injury status and performance will be monitored throughout the cricket season through either telephonically, via whatsapp or email. You are welcome to record injury status and bowling performance in hard copy should you prefer.

Are there any risks of taking part in this study?
The test is non-invasive and has minor side effects which may include skin irritation from the reflective marker placements.

What are the benefits of taking part in the study?
Your balance scores will be measured and given to you. Non-identifiable, general results will be made available to all of you that participate at the end of the study. No monetary award will be given for taking part in this study. We hope that this research will give us scientific information as to some of the factors that contribute to injury and performance predictions and thus be of a possible benefit to you once the study is complete.

You will be given pertinent information on the study while involved in the project and after the results are available.

Participation is voluntary and refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. Furthermore, you may discontinue participation at any time without prejudice or questioning

Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if

required by law.  Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the Research Ethics Committee. To ensure confidentiality of participants, each participant will be assigned a study number. The key to the study numbers assigned is kept in the possession of the researcher only. Names of participants are only to be written on the consent form and not on the questionnaire. In addition, consent forms are kept separately from the questionnaires. All information will be confidential and will be used only for the purpose intended in this study.

If you require additional information, please do not hesitate to contact me on 082 494 8102 or send an email to taskeen.hoosen@gmail.com.

For more information on, or for the reporting of ethical concerns, you may contact the chair of the Human Research Ethics Committee of the University of the Witwatersrand:
Prof Cleaton Jones; Tel: 011-717-2700

Should you wish to participate please fill in the consent form attached;

Kind Regards

Taskeen Hoosen

Appendix E CONSENT FORM

STUDY TITLE: The Star Excursion Balance Test, Kinematics and Injury

INVESTIGATORS: Taskeen Hoosen

I_____ (e-mail address:_____ and cell phone number: _____ ). Hereby agree to participate in the study as described to me in the information sheet. By signing this form I am agreeing to filling in the questionnaire and for my balance test to be video recorded. I am satisfied that I have been informed by the researchers about the nature and purpose of the study. I acknowledge that I have been given contact details, should I have any additional queries for the investigators. I declare that I am fit to participate in the study according to inclusion and exclusion criteria stated in the information sheet. I am aware that I will not be exposed to any additional risks other than skin irritation from the electrode or reflective marker placements. I understand that I can withdraw from the study at any time and I will not be penalised and that I am not obliged to take part and that participation is voluntary. I understand that there are no monetary rewards for my participation

Printed name Signature Date

_____ _____ _____

Researcher name Signature Date

_____ _____ _____

For office use only:

Study number: _____

Appendix F ETHICAL CLEARANCE CERTIFICATE

R14/49 Taskeen Hoosen

## HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

## CLEARANCE CERTIFICATE NO. M150463

| | |
|---|---|
| **NAME: (Principal Investigator)** | Taskeen Hoosen |
| **DEPARTMENT:** | Physiotherapy<br>Wits Physiotherapy Movement Analysis Laboratory |
| **PROJECT TITLE:** | The Y-Balance Test: Kinematics, EMG, Injury and Perfomance in Cricketers |
| **DATE CONSIDERED:** | 24/04/2015 |
| **DECISION:** | Approved unconditionally |
| **CONDITIONS:** | |
| **SUPERVISOR:** | Benita Oliver and Nadia Gillion |
| **APPROVED BY:** | Professor P Cleaton-Jones, Chairperson, HREC (Medical) |
| **DATE OF APPROVAL:** | 11/09/2015 |

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

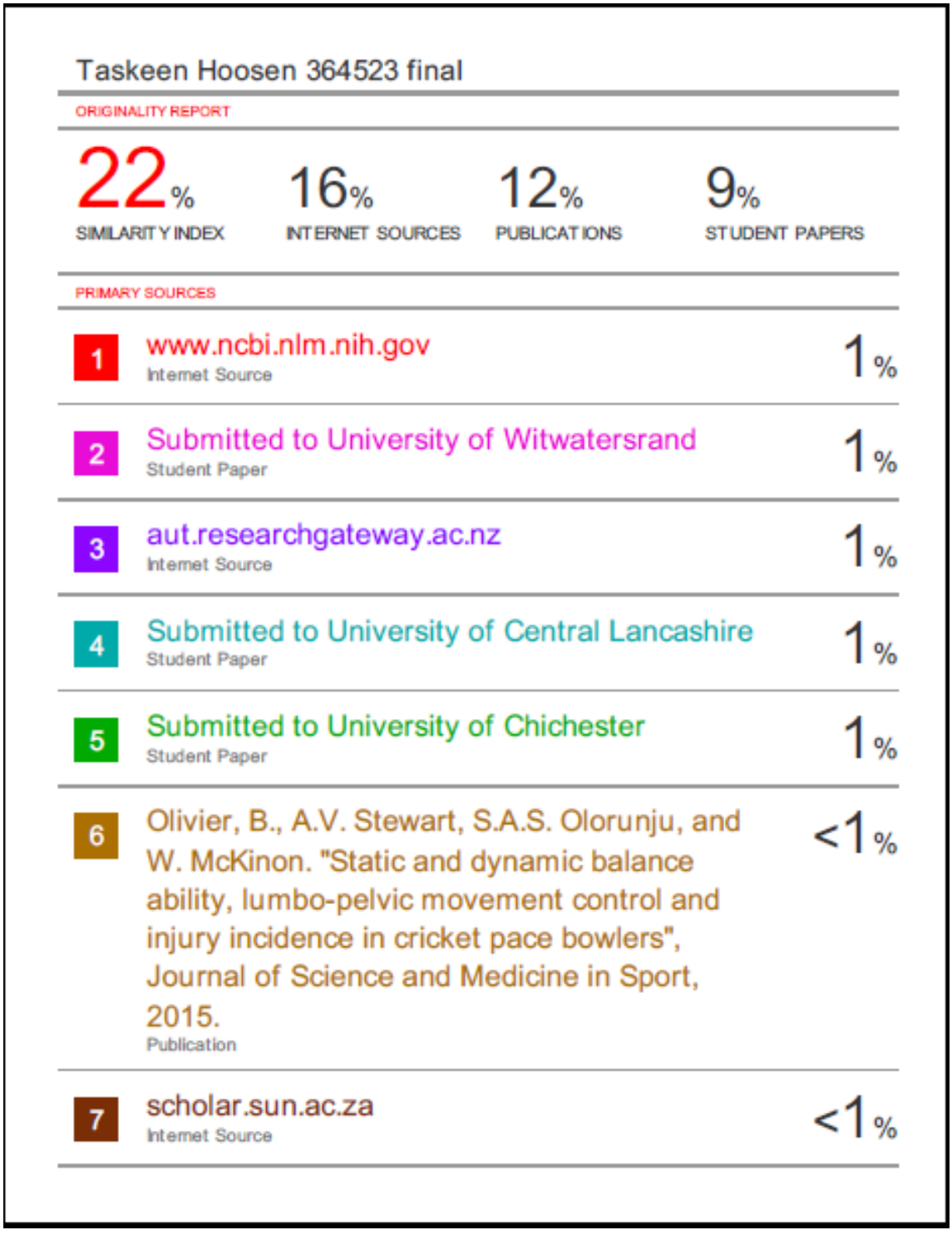
**DECLARATION OF INVESTIGATORS**

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.**

Principal Investigator Signature Date

**PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES**

Appendix G TURNITIN REPORT



Taskeen Hoosen 364523 final

ORIGINALITY REPORT

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