FACTORS ASSOCIATED WITH HIGH BALL RELEASE SPEEDS IN ELITE PACE BOWLERS IN SOUTH AFRICA

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UNIVERSITY OF THE
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Declaration

I, Rumbidzai Esnath Murambasvina, declare that this Research Report is my own, unaided work. It is being submitted for the Masters in Physiotherapy (Neuromusculoskeletal) degree at the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at any other University.

_Rumbidzai E. Murambasvina_____ ________________________________

Name of candidate Signature of candidate

_____27th___ day of ___SEPTEMBER_______ 20__24___ in____Johannesburg_________

Abstract

Background

Fast bowling is an important skill contributing to the success of cricket teams. Past research has shown that there is a correlation between some anthropometric and biomechanical factors and ball release speed. However, there is no clear consensus on which factors, specifically, contribute to high ball release speeds. This study therefore aims to investigate the age, sex, anthropometric, and biomechanical factors associated with ball release speed.

Method

A secondary data analysis was done of 53 biomechanics reports of elite cricket pace bowlers. The reports of uninjured elite bowlers who were aged 18 and above and were contracted to Cricket South Africa were included in the study. The primary study was conducted at the cricket nets of Cricket South Africa Centre of Excellence in Pretoria. The XSens inertial sensor was used to record the bowler's bowling techniques. Ball release speed was measured using a hand-held radar speed gun (Stalker ATS, Texas). Accuracy was measured using a target behind the stumps based on the target used by Cricket Australia. The correlation between age, sex, anthropometric, and biomechanical factors with ball release speed was tested using Spearman's correlation.

Results

The male pace bowlers (age 24.1±0.3; height 1.9±0.8m; mass 84.0±10.4; BMI 23.9±5.0kg/m^2) had a higher mean ball release speed (128.2±2.4 km/h) than their female counterparts (age 24.8±3.7; height 1.6±0.1; mass 61.9 ±7.8; BMI 22.5 ± 2.3) who had a ball release speed of 95.2 ± 3.6km/h. There was a positive correlation between age (ρ=0.353, p=0.005), mass (ρ=0.230, p=0.077) and BMI (ρ= 0.442, p<0.001) in female pace bowlers whereas in males there was a positive correlation between height and ball release speed (ρ=0.256, p=0.002). There was a positive correlation between front knee angle at front foot placement and ball release speed (ρ= 0.203, p=0.016; ρ=0.182, p=0.140) for both males and females respectively.

Conclusion

Physiotherapists can target relevant muscle groups when training pace bowlers in order to enhance their performance. Female and male pace bowlers use different strategies to generate ball release speeds and there is a need for further research into female cricket in order to better inform coaching and rehabilitation practices.

Key words- cricket, high ball release speeds, biomechanical, anthropometric, factors, pace bowlers

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List of abbreviations

BFP - Back Foot Placement

BMI - Body Mass Index

BRS - Ball release speed

FFP - Front Foot Placement

SD - Standard Deviation

CHAPTER 1: INTRODUCTION AND SCOPE OF THE RESEARCH REPORT

1.1 Introduction

Cricket is an international sport that is played in many countries by eleven team players in each team. Cricket players have different roles in the game, with pace bowlers being one of the key performers during the game and contributing to the success of any bowling side (Portus *et al.*, 2007; Wormgoor, Harden and Mckinon, 2010; Glazier and Wheat, 2014). There are two main bowling techniques in cricket, namely pace bowling, which is commonly referred to as fast bowling and spin (slow) bowling. Pace bowlers can further be categorized as medium, fast-medium, and fast bowlers (Olivier *et al.*, 2016).

The main aim of pace bowlers is getting the other team's batters to miss the ball by failing to anticipate its direction or speed or by reacting in a slower pace (Burnett, 1996; Felton, Lister, Worthington, 2018). Studies have shown that a fast moving ball gives the batter anxiety and increases their chance of missing it. High ball release speeds give batters less time to decide which particular stroke to use when batting (Salter, Sinclair and Portus, 2007; Worthington, King and Ranson, 2013; Felton, Lister, Worthington, 2018; Felton, McCaig and King, 2023; Lyons, 2023) and force them to rely on automated movements to execute the stroke (Zhang, Unka and Liu, 2011). A cricket team's success is improved when the opposing batman has fewer chances to score or fails to score at all (Portus *et al.*, 2004; Loram *et al.*, 2005; De Asha *et al.*, 2009; Wormgoor, Harden and Mckinon, 2010; Feros, Young and O'Brien, 2019). The goal of teams is therefore to train their pace bowlers so that they can generate high ball release speeds (Wormgoor, Harden and Mckinon, 2010; Glazier and Wheat, 2014; Felton, Lister, Worthington, 2018).

The bowling action is divided into three major stages which are back foot contact, front foot contact and ball release (Burnett, 1996). Different movements of the joints occurring during these three stages contribute to high ball release speeds. While some research focuses on injury prevalence and prevention, factors contributing to fast bowling performance are a critical part of the cricket game and are becoming increasingly important to the coaching field (Glazier & Wheat, 2014).

Research carried out in the past has established some of these factors including anthropometric factors (Loram *et al.*, 2005; Singh A, Singh, A. K, Singh, 2015), biomechanical factors to do with the bowler's technique (Loram *et al.*, 2005; Glazier and Wheat, 2014), good technique (Thander and Prasad, 2019) as well as the bowler's muscle strength (Loram *et al.*, 2005). Biomechanical factors that were seen to contribute to ball release speeds include shoulder alignment, knee and hip kinematics, trunk flexion, pelvis rotation as well as centre of mass, while anthropometric factors that were cited as being beneficial to ball release speed were longer lower limb lengths (and thus height) (Thander and Prasad, 2019).

A correlation between the knee angle during front foot placement and ball release speeds has been shown in past research (Loram *et al.*, 2005; Wormgoor, Harden and Mckinon, 2010). Bowlers with the fastest ball release speeds had a straighter knee angle during front foot placement (Loram *et al.*, 2005; Portus *et al.*, 2007; Worthington, King and Ranson, 2013). A straighter knee gives more stability to the cricketer and creates a more effective lever which in turn increases the ball release speed (Loram *et al.*, 2005).

There has been a suggestion that high ball release speeds are associated with a high degree of trunk flexion (Worthington, King and Ranson, 2013; Felton, Lister, Worthington, 2018). Olivier, Stewart, Green, McKinon (2013) showed that trunk side flexion to the contralateral side contributes to ball release speeds. In contrast to this, Thander (2019) and Alderson (2007) found that there was a moderately negative correlation between trunk side flexion and ball release speeds.

Bowlers have been shown to have different techniques when it comes to bowling depending on their amount of shoulder and hip movements. This brought about a bowling action classification which classified bowlers into side-on, semi-open, front-on mixed, side-on mixed and mixed bowlers (Portus *et al.*, 2004). A side on technique is "*when the shoulder segment angle is less than 210º at back foot, a hip- shoulder separation angle less than 30º at back foot contact, and shoulder counter rotation less than 30º"* (Portus *et al.*, 2007; page 266). A semi-open technique is "*one in which the shoulder segment angle is from 210º to 240º at back foot contact, a hip separation angle less than 30º at back foot contact and shoulder counter rotation less than 30º*" (Portus *et al.*, 2007; page 266). A front- on technique is "*one in which the shoulder segment angle is greater than 240º at back foot contact, the hip-shoulder separation angle is less than 30º at back foot contact and shoulder counter rotation is less than 30º*" (Portus *et al.*, 2007; page 266). A mixed technique is "*one in which the hip-shoulder separation angle is equal to or greater than 30º at back foot contact or shoulder counter rotation greater than or equal to 30º*" (Portus *et al.*, 2007; page 266). These classifications, however, varied in literature (Portus *et al.*, 2004; Ferdinands *et al.*, 2010; Wormgoor, Harden and Mckinon, 2010) and were shown to be difficult for coaches to accurately classify.

Furthermore, there is a suggestion in the literature that the side-on technique generates high ball release speed as it is associated with a higher range of pelvic rotation and thoracic movement which generate high ball release speeds (Glazier and Wheat, 2014). Bowlers who used the front-on delivery were shown to be prone to low back injuries (Elliott, Foster and Gray, 1986).

There is need for more research on factors contributing to high ball release speeds in order to inform cricket teams, physiotherapists working with cricket teams and coaching manuals because teams that produce high ball release speeds have high success rates. There is limited literature on the factors associated with ball release speed (Salter, Sinclair and Portus, 2007; Worthington, King and Ranson, 2013). There is also no clear consensus in research already done on the factors that contribute to high ball release speeds (Salter, Sinclair and Portus, 2007; Phillips, 2011; Worthington, King and Ranson, 2013). An investigation into these factors is therefore imperative.

1.2 Problem Statement

There is no consensus in the literature on the factors that are associated with high ball release speed as well as specifically which biomechanical factors contribute to high ball release speeds (Glazier, Paradisis and Cooper, 2000; Worthington, King and Ranson, 2013; Middleton *et al.*, 2016). There is also a scarcity of research investigating the biomechanics using inertial sensors and yet inertial sensors have been shown to be more accurate in collecting biomechanical data during movement as opposed to optical systems. Therefore, there is a need to determine the factors that are associated with ball release speeds among elite Cricket pace bowlers, using inertial measuring units, so as to provide evidence-based information for cricket coaching and rehabilitation.

1.3 Research Question

What are the factors associated with high ball release speeds among elite cricket pace bowlers?

1.4 Aim of the Study

This study aims to determine the factors associated with high ball release speeds among elite pace bowlers.

1.5 Objectives of the Study

The objectives of this study are to:

1. Determine the age, sex and anthropometric factors associated with high ball release speeds among elite pace bowlers.
2. Determine the biomechanical factors associated with high ball release speeds among elite pace bowlers.

1.6 Significance of the Study

Findings from our study can be used to inform experimental research aimed at modifying biomechanical variables to ultimately enhance performance. These studies can be used to inform physiotherapists on optimum muscle strengthening programs to use for pace bowlers. Biomechanical variables explored using inertial sensors will also help form a basis for future research seeing that studies investigating the bowling action using inertial sensors are scarce.

1.7 Organisation of the research report

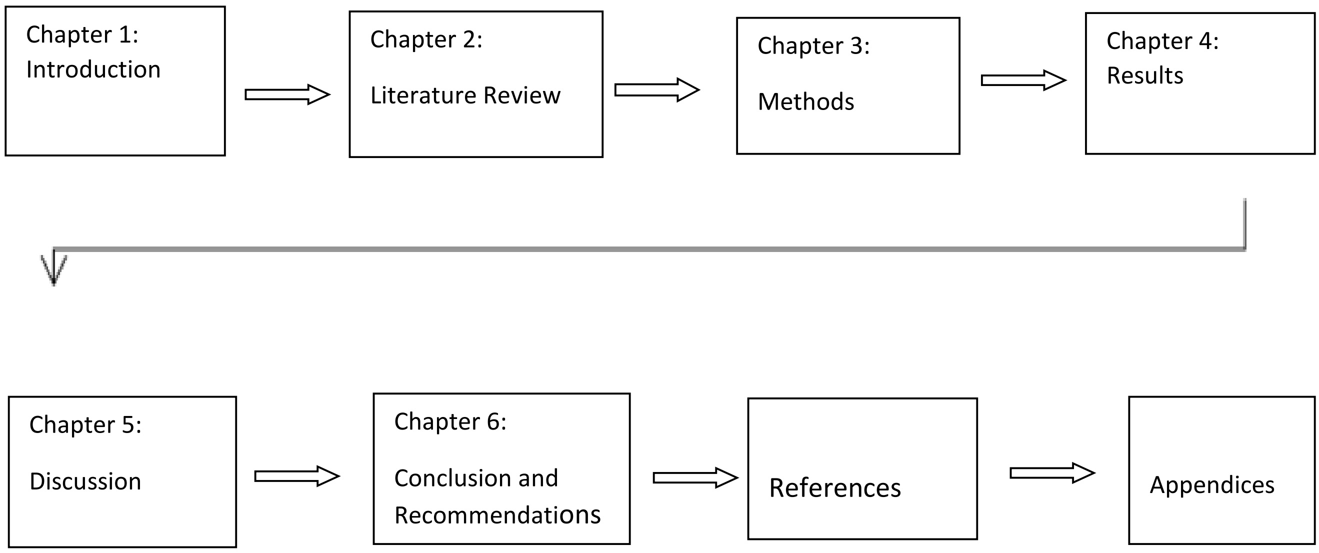


Figure 1.1: Outline of the research report

1.8 Conclusion

This chapter presented the introduction, problem statement, objectives of the study, an outline of the aim of the study and a motivation of the importance of this study. The next chapter will present a review of the available literature on the factors that were correlated with ball release speed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A literature review of previous studies which looked at factors that were correlated with ball release speed will be carried out in this chapter. The literature review will outline what previous studies have highlighted as factors that contribute to ball release speeds. This will enable a comparison of the findings of this study to previous studies and a deeper understanding of the role of age, sex, anthropometrics, and kinematics in generating ball release speed. An outline of the different movements of the bowling action and their role in the generation of ball release speed will be carried out. This chapter will also explore the different forces acting on the body during these movements. It will also explore the difference between the strategies used by male and female pace bowlers in generating ball release speeds.

2.2 Search Strategy

A literature search was done to identify research on factors that contribute to high ball release speeds. Articles were sourced from PubMed, Scopus, Research Gate and Google Scholar. The search was for articles written in English. Systematic reviews that looked at past research were also included. The keywords used to search for the articles were "factors, contributions, associated, determinants, anthropometric factors, biomechanical factors, socio-demographic factors, cricket pace bowlers, cricket fast bowlers, male pace bowlers, female pace bowlers and ball release speed". All articles that fit these criteria and were published within twenty years of this research were included in this literature review. However, due to the paucity of literature, studies from earlier years were also included to add value to the discussion.

2.3 The bowling action

A bowler's ball release speed is dependent on their bowling action. The bowling delivery is considered as the actions that a cricketer makes to deliver the ball to the opposing team and it is made up of various complex movements of the different segments of the body (Thander, 2023). This stage is regarded as the most important because the actions carried out in this phase determine ball release speeds. Moreover, the body withstands significant amounts of forces going through it. The bowling action is divided into three major stages, namely, back foot contact, front foot contact and ball release (Burnett, 1996). It starts during the delivery stride before the ball is released (Thiagarajan *et al.*, 2015) and the delivery stride is considered as "the period between back foot placement and the moment that the ball is released" (Glazier and Wheat, 2014).

The delivery stride is marked by the first stage which is back foot contact. Back foot contact is defined as "*the second last foot contact event before the bowler releases the ball. It occurs at the beginning of the delivery stride when the bowler's right foot (right-arm bowler) makes contact with the ground"* (Middleton, 2011, page 10). The positioning of the shoulder and hips is influenced by the back foot contact and this contributes to the overall ball release speed (Thander, 2023). The back foot holds the majority of the bowler's weight at this point (Thander, 2023). Front foot contact is "*the last foot contact event before the bowler releases the ball. It occurs when the left foot (right-arm bowler) makes contact with, and is flat on, the ground*" (Middleton, 2011, page 10). Front foot placement occurs at approximately 70% of the delivery stride (Glazier and Wheat, 2014). Ball release is the moment "*the ball breaks contact with the bowling hand*" (Middleton, 2011, page 11; Thander, 2019).

The above phases describe how the bowler moves from the moment the delivery stride begins up to the time he releases the ball to the opposing team and are the subject of assessment in this study as the different ranges of motion of the different joints play a role in the outcome of the ultimate ball release speed.

2.4 Factors associated with ball release speed

A number of factors have been outlined in literature as having a correlation with ball release speed. These include socio-demographic, biomechanical (Glazier, Paradisis and Cooper, 2000; Loram *et al.*, 2005; Portus *et al.*, 2007), anthropometric (Glazier, Paradisis and Cooper, 2000; Loram *et al.*, 2005; Pyne *et al.*, 2006; Wormgoor, Harden and Mckinon, 2010; Koley, 2011; Singh A, Singh, A. K, Singh, 2015), technique (Salter, Sinclair and Portus, 2007; Middleton, 2011) as well as muscle strength (Loram *et al.*, 2005; Pyne *et al.*, 2006; Letter *et al.*, 2022b).

2.4.1 Age

Previous research noted that there is a positive correlation between older age and ball release speed. A study by Pyne *et al.* (2006) was done to compare senior and junior pace bowlers and the higher ball release speeds generated by senior pace bowlers was attributed to development of both physical qualities and experience of the older pace bowlers. The seniors in this study were substantially taller and heavier than their junior counterparts and had much more iso-inertial strength of the upper body and lower body. The conclusion was that growth and maturation of the senior bowlers were the main reasons for their being faster than their junior counterparts (Pyne *et al.*, 2006). However, the senior bowlers in our study were 23.9 ± 4.8 years and the juniors were 14.8 ±1.3 years therefore inferences can only be made to bowlers in this age group as we cannot conclude whether the ball release speeds then peaks at a certain age or keeps increasing as the age increases. There were similar findings in adolescent pace bowlers who were investigated by Olivier F. M., Olivier B. and Mnguni, (2022), they found a moderate positive correlation between older age and ball release speed (r=0.43, p=0.003).

Research done by Letter *et al.* (2022a) has shown that most of the physical qualities of pace bowlers improved as they got older and they suggested that most of these physical qualities were likely to contribute to higher ball release speeds. This may also be the reason why older pace bowlers in their study had higher ball release speeds than their younger counterparts (Letter *et al.*, 2022a). In their findings, they noted that female pace bowlers in the age range of 18-22 years had more statistically significant findings of improved absolute body strength than their male counterparts therefore this may mean that females depend more on the contribution of physical qualities to ball release speeds than their male pace bowlers.

Stockill and Bartlett (1994) suggested that senior pace bowlers had faster ball release speeds than their juniors due to their taller statures which meant they had longer limbs and a greater tangential distance. They also noted that senior pace bowlers had higher approach speeds than the younger pace bowlers and that with age, pace bowlers had improved experience therefore they generated faster ball release speeds than their younger counterparts.

In the study by Pyne *et al.* (2006) there were similar findings and the differences in body mass and upper body strength accounted for the differences in ball release speed between young fast bowlers and their senior counterparts. In their study where they compared first-class senior male fast bowlers and junior representative male fast bowlers they found that the older pace bowlers had a significant correlation with ball release speed. However, the big age discrepancy in their subjects probably played a huge role as the senior pace bowlers were much older and probably had a lot more experience than their junior counterparts.

2.4.2 Sex

The general consensus in research is that male pace bowlers have higher ball release speeds than females (Felton, Lister, Worthington, 2018). Felton, Lister, Worthington (2018) suggested that this was likely due to the fact that females had slower run-up speeds which gave them less whole body linear momentum and ultimately affected their ball release speeds. Females were also generally shorter than males, and had shorter torsos and shorter arm lengths (Felton, Lister, Worthington, 2018). It was also shown that females take longer to transition during the period between front foot contact and ball release and this contributes to lower speeds as the ball is released at a later stage as compared to their male counterparts (Felton, Lister, Worthington, 2018). Savage, T N; Portus M. (2002) attributed the lower ball release speeds in female pace bowlers to gender differences citing that females often are shorter than their male counterparts and also have decreased strength.

It has been suggested that the morphological differences that exist between male and female pace bowlers result in a difference in bowling biomechanics, thus impacting their ball release speeds and the factors determining them (Letter *et al.*, 2022b). Studies have shown that female pace bowlers tend to use more of the upper body to generate ball release speeds and have a higher range of trunk rotation than their male counterparts. Their run-up speeds are also less and they spend more time during the front foot placement as compared to males (Letter *et al.*, 2022b). It was also shown that the contribution of physical qualities to ball release speed differs with the sexes (Letter *et al.*, 2022a). In their study, Felton, Lister, Worthington (2018) noted that the two groups use different techniques to generate ball release speeds as they suggested that females rotated their pelvis more than their male counterparts and this helped them generate ball release speeds.

2.4.3 Anthropometric factors

Anthropometry has been used in various sporting disciplines to establish the relationship between different body structures and different tasks and particularly in sports, to establish their relationship to performance and generation of desired end goals. Even though each individual is unique, there has been evidence that different populations tend to follow a curve of normal distribution and have general characteristics or physique that is almost the same (Koley, 2011). With this generalisation, one can then predict that people with a certain type of physique would generally thrive in certain sporting disciplines than others. It has been shown that it is possible to determine which particular sport a person will excel in, depending on the anthropometric characteristics which they possess (Koley, 2011).

Anthropometry has been used in the field of cricket and it has been noted that international cricket players tend to have a tall, athletic physique. It was also shown that certain morphological differences characterize each group of players (Koley, 2011). Bowlers tend to have a taller physique with longer legs and broad shoulders while batters have a shorter and lighter physique with relatively more body fat than bowlers. All-rounders tend to have characteristics similar to both bowlers and batters (Koley, 2011). Middleton (2011) agrees with this notion, stating that taller players become successful fast bowlers. However, other authors noted that even though cricket players tend to be more physically fit than the sedentary population, there were no significant differences between the players themselves (Middleton, 2011). Authors such as Stuelcken, Pyne and Sinclair (2007) noted that there was a difference between male and female elite bowlers after testing measurements of their length, girth, skinfolds and breadths. Male pace bowlers had longer lengths as well as larger breadths and girths as compared to their female counterparts. The male pace bowlers in their study had mean height of 1.88± 0.007m and a mean mass of 87.9 ± 8.2kg versus a mean height and mass of 1.77 ± 0.005m and 66.2 ± 7.5 kg respectively for their female counterparts.

There have been some studies done in the past to investigate the contribution that anthropometric factors make to ball release speed (Wormgoor, Harden and Mckinon, 2010; Phillips, 2011; Johnstone *et al.*, 2014). Despite the efforts of previous researchers, the exact role of anthropometric characteristics is still unclear (Wormgoor, Harden and Mckinon, 2010). Anthropometric factors such as height, weight, BMI, body composition and somatotype values have been shown to be correlated to ball release speed (Wormgoor, Harden and Mckinon, 2010; Johnstone *et al.*, 2014). However, some authors suggest that there is very little, if any contribution, made by anthropometric factors to ball release speed (Wormgoor, Harden and Mckinon, 2010; Phillips, 2011).

2.4.3.1 Height

Height is considered to be an important attribute for fast bowlers with statistics showing that the most successful elite pace bowlers have a tall stature (Middleton, 2011; Johnstone *et al.*, 2014; Singh A, Singh, A. K, Singh, 2015). It is shown that more than 80% of elite pace bowlers that have the best ball release speeds have a height of over 1.83m (Middleton, 2011; Johnstone *et al.*, 2014). A tall stature has a substantial impact on the final output of ball release speed (Ferdinands *et al.*, 2010; Lyons, 2023).

Research carried out in the past showed that taller bowlers tend to have higher ball release speeds as compared to their shorter counterparts (Felton, Lister, Worthington, 2018; Felton, McCaig and King, 2023). Middleton (2011) and Felton, Lister, Worthington (2018) showed that longer lower limbs (and hence a greater height) contributed to high ball release speeds. Singh A, Singh, A. K, Singh (2015) found a moderate positive correlation between height and ball release speed (r=0.4241, p=0.001) in their study of 45 male inter-collegiate fast bowlers. Olivier et al. (2019) also found a moderate positive correlation between height and ball release speed (r=0.49; p=0.001). Felton, Lister, Worthington (2018) postulated that 68.8% of the differences in ball release speed were because of height while Lyons (2023) attributed 53% of the ball release speeds generated by female pace bowlers to their height.

A tall stature is believed to aid ball release speed by attenuating forces. The higher the distance from which a ball falls, the harder it bounces when it lands on the ground and this propels the ball faster (Johnstone *et al.*, 2014; Singh A, Singh, A. K, Singh, 2015; Feros, Young and O'Brien, 2019). Tall pace bowlers have longer levers (Middleton, 2011; Lyons, 2023) and this increases ball release speeds because the ball and axis of rotation are further from each other (Middleton, 2011). It has also been suggested that a taller height increases accuracy thereby increasing ball release speeds (Singh A, Singh, A. K, Singh, 2015).

Contrary to the above findings, Wormgoor, Harden and Mckinon (2010) did not find any correlation between height and ball release speed in bowlers who played for premier league clubs in Gauteng, South Africa. In their study, bowlers with a mean age of 22.0 had their measurements of height, body mass, body composition and body mass index as well as somatotype values and selected skeletal lengths measured. They investigated the relationships of these variables with ball release speed and none of them were found to have a correlation with ball release speed. Though they acknowledge that a greater height may have a mechanical advantage, they postulate that their results probably mean that height has a minor contribution to ball release speeds, if any.

2.4.3.2 Body mass

Some authors showed a positive correlation between body mass and ball release speed (Pyne *et al.*, 2006; Feros, Young and O'Brien, 2019). Stuelcken, Pyne and Sinclair (2007) demonstrated that players with a larger physical stature and greater strength tend to bowl faster than their smaller counterparts. In the study by Singh A, Singh, A. K, Singh (2015), there was a weak positive correlation between mass and ball release speed (r=0.1060). This was also supported by Felton, Lister, Worthington (2018) who showed that male pace bowlers tend to have bigger statures and heavier masses than their female counterparts therefore their ball release speeds were higher. However, in adolescent pace bowlers investigated by Olivier F. M., Olivier B., and Mnguni (2022), there was a negative correlation between mass and ball release speed (r=-0.39, p=0.77).

Other scholars did not find any correlation between mass and ball release speed (Wormgoor, Harden and Mckinon, 2010; Phillips, 2011; Lyons, 2023). In their study, Lyons (2023) confirmed that there was no correlation between mass and ball release speed in female pace bowlers as outlined in previous research carried out with male pace bowlers by Wormgoor, Harden and Mckinon. (2010). In their study of junior, emerging and national cricket bowlers, Phillips (2011) also did not find any correlation between mass and ball release speed. However, they suggest that the small sample size in their study could have influenced these results and recommended further investigations into the roles of anthropometric factors in ball release speed.

2.4.4 Biomechanical factors

There has been evidence that different biomechanical factors are correlated to ball release speeds and these included trunk side flexion, trunk rotation, knee flexion, hip flexion, pelvis alignment, shoulder alignment in the transverse plane at front foot placement, the front knee flexion between foot placement and ball release (Portus *et al.*, 2004; Loram *et al.*, 2005; Wormgoor, Harden and Mckinon, 2010), and trunk alignment (Worthington, King and Ranson, 2013). This literature review will look at trunk side flexion, trunk rotation, pelvis rotation, hip flexion and knee flexion during the different stages of the bowling action.

2.4.4.1 Trunk side flexion

There has been evidence in past research of a relationship between trunk side flexion and ball release speed. Olivier, Stewart, Green, McKinon (2013) looked at the contribution of global trunk side flexion as well as segmental trunk side flexion to ball release speed in 18 to 26 year old pace bowlers. Their results showed a positive correlation between global trunk side flexion and ball release speed as well as segmental lateral flexion to the left at front foot placement and ball release speed. More global lateral flexion and more lateral flexion to the left at the T7, T10 and L1 levels led to higher ball release speeds (Olivier, Stewart, Green, McKinon, 2013). They postulated that bowlers use lateral flexion of the trunk to the contralateral side to generate ball release speed, therefore in right handed bowlers, lateral flexion to the left is linked to an increase in ball release speeds. Olivier, Stewart, Green, McKinon (2013) suggested that lateral flexion contributed to ball release speeds by generating an increased power in the trunk muscles.

Middleton (2011) pointed out that an increase in trunk side flexion had a relationship with high ball release speeds, though the author argues that the contribution of trunk side flexion and rotation to ball release speeds was trivial. Prasad (2015) postulated that an increase in trunk side flexion increased the rotation in the shoulder of the bowling arm and thus increased ball release speed (Prasad, 2015). Phillips (2011) noted that junior cricket bowlers used trunk side flexion to generate ball release speeds at front foot placement.

Contrary to these findings, some studies have shown a negative correlation between trunk side flexion and ball release speed. A study by Alderson (2007) aimed to identify whether ball release speeds depended on certain biomechanical characteristics. Their findings suggested that high ball release speeds were not dependent on trunk lateral flexion as there was a significant moderate negative correlation between trunk side flexion and ball release speed. This means that, in order to achieve high ball release speeds, a pace bowler has to reduce the extent to which they bend to the side (Alderson *et al.*, 2007). Thander (2019) agrees with this notion and also found that there was a moderate negative correlation between trunk side flexion and ball release speeds. In their study comparing junior, emerging and national cricket players, (Phillips, 2011) had the same findings and their results showed that there was a negative correlation between trunk side flexion at front foot placement and ball release speed in both emerging and national cricket players, unlike their junior counterparts.

2.4.4.2 Trunk Rotation

Trunk rotation was shown to contribute to high ball release speeds. In the study by Olivier, Stewart, Green, McKinon (2013) , they found that trunk rotation to the left increased ball release speed. According to Prasad (2015), trunk rotation was shown to contribute to ball release speeds by rapidly increasing the speed of the bowling shoulder. Feros, Young and O'Brien (2019) pointed out that fast bowlers counter-rotated their trunk more at front foot placement. Trunk rotation, together with trunk flexion, were thought to contribute to ball release speed by increasing the angular velocity of the bowling arm (Glazier & Wheat 2014).

Previous research has postulated that female pace bowlers have a tendency to use rotation of the trunk more than their male counterparts to generate high ball release speeds (Letter *et al.*, 2022a; Lyons, 2023). This leads to a delay in the bowling arm and propels the arm further thus generating ball release speed (Felton, Lister, Worthington, 2018; Lyons, 2023). A more delayed bowling arm also makes it easier to direct the ball towards the target (Lyons, 2023). Female pace bowlers were shown to spend more time during front foot contact as compared to males. This enables them to use the large rotational muscles of the body to propel the ball forward (Letter *et al.*, 2022a).

2.4.4.3 Pelvis Rotation

Research has shown that trunk and pelvic rotation during the bowling phases contribute to ball release speed (Ferdinands *et al.*, 2010; Phillips, 2011; Glazier and Wheat, 2014). Some studies have highlighted a relationship between pelvic and thoracic movement in the transverse plane and highlighted that a greater pelvic and thoracic rotation is related to higher ball release speeds (Ferdinands *et al.*, 2010; Phillips, 2011; Glazier and Wheat, 2014). Studies have shown that a greater range of pelvis rotation leads to higher ball release speeds. A greater range of pelvis rotation in the transverse plane enables players to move through a larger arc and thereby contributing to a higher ball release speed. Pelvis rotation increases the angular acceleration by pushing back the bowling arm and causing a strong stretch-shortening cycle in the anterior shoulder muscles thereby contributing to high ball release speeds

(Ferdinands *et al.*, 2010). Phillips (2011) suggests that pelvis rotation assists with the transfer of kinetic energy along the kinetic chain. In the study by Felton, Lister, Worthington (2018), there was suggestion that female pace bowlers tend to rotate their pelvis more than males in order to generate ball release speeds.

Various authors quantified the contribution of different joint motions to ball release speed. Glazier, Paradisis and Cooper (2000) reported that pelvis rotation contributed 2% to the total ball release speed, while Zhang, Unka and Liu (2011) reported that pelvis rotation contributed 12% to ball release speed. However, the researchers highlighted the need to be careful in adopting these results. They explained that the method of immobilising body segments to approximate how much each segment contributes to ball release speed assumes that the immobilised parts do not contribute at that point which is inaccurate. Elliot et al. (1986) also showed that pelvis rotation contributed 15% and pelvis and trunk flexion contributed 13% to the final ball release speed. Glazier, Paradisis and Cooper (2000) postulated that trunk flexion contributed 6% and pelvis rotation contributed 2% to the total ball release speed. Zhang, Unka and Liu (2011) showed that the contributions of the different segments were pelvis rotation 12% and trunk flexion 29%.

2.4.4.4 Non-dominant hip flexion (front hip)

The role of hip flexion in ball release speeds is not extensively covered in research. Previous research shows a negative correlation between hip flexion and ball release speed (Felton, Lister, Worthington, 2018). Felton, Lister, Worthington (2018) showed a difference between the hip flexion angles of male and female pace bowlers at back foot placement. Male pace bowlers were shown to have greater hip extension at back foot placement and this resulted in a more leaned back posture when coupled with trunk extension.

2.4.4.5 Dominant hip flexion (back hip)

It has been suggested that the back leg does not have a big role in the generation of ball release speeds. As a result, there is not much research focusing on it. Theoretically, the rear hip flexion reduces the moment of inertia around the front hip and increases trunk flexion which increases the ball release speed. Hip flexion of the back leg may also help maintain stability as well as the linear momentum (Felton, Yeadon and King, 2020).

2.4.4.6 Non-dominant knee flexion (front knee)

There has been considerable research around the alignment of the front knee during bowling and the general consensus is that there is a positive correlation between front knee extension during front foot placement and ball release speeds (Loram *et al.*, 2005; Wormgoor, Harden and Mckinon, 2010; Middleton *et al.* 2013; Glazier and Wheat, 2014; Feros, Young and O'Brien, 2019). Bowlers with the fastest ball release speeds have a smaller degree of flexion during front foot placement (Hurrion *et al.*, 2002; Portus *et al.*, 2004, 2007; Loram *et al.*, 2005; Pyne *et al.*, 2006; Worthington, King and Ranson, 2013; Glazier and Wheat, 2014). In their study of pace bowlers between the ages of 18 and 26 years, Olivier, Stewart, Green, McKinon (2013) found that there was a fair relationship between front knee extension and ball release speed, that is, the closer the knee was to 180º, the higher the ball release speed generated.

Feros, Young and O'Brien (2019) postulated that an extended knee at front foot placement was associated with better bowling accuracy and therefore resulted in high ball release speeds. A straighter knee gives more stability to the cricketer and creates a more effective lever for the body to rotate on and this in turn increases the ball release speed (Loram *et al.*, 2005; Wormgoor, Harden and Mckinon, 2010; Middleton, 2011; Olivier, Stewart, Green, McKinon, 2013; Glazier and Wheat, 2014; Olivier *et al.*, 2016; Thander, 2023) as it maintains the angular velocity (Middleton, 2011). A straighter knee also increases the radial distance between the front foot and the bowler's extended arm which increases the tangential velocity and increases ball release speed (Bartlett *et al.,* 1996; Wormgoor, Harden and Mckinon, 2010; Olivier; Stewart; Green; McKinon, 2013; Feros *et al.,* 2015; Olivier *et al.*, 2016). Portus *et al.* (2004), Portus *et al.* (2007), and Worthington, King and Ranson (2013) further add that a straighter knee may facilitate easier transfer of kinetic energy to the ball and increase the ball release speed. Wormgoor, Harden and Mckinon (2010) also agree with this notion and state that the more extended knee offers a rigid lever which makes the transfer of kinetic energy much easier and contributes to high ball release speeds. A more extended knee also increases the quadriceps muscle input and creates an extra bounce. This adds on to the ball release height and in turn increases the ball release speed (Portus *et al.*, 2004).

Some authors have postulated that landing with a straighter knee helps to produce higher ground reaction forces and these in turn contribute to high ball release speeds (Glazier and Wheat, 2014). Portus *et al.* (2004) also asserted this and showed that bowlers with a straighter knee experienced higher peak forces. However, Worthington, King and Ranson (2013) showed that the angle of the knee has little to no impact on ground reaction forces and argued that it was rather the foot angle and the plant angle that influenced ground reaction forces rather than the angle of the knee. The foot angle was defined as, "*the angle between the vector adjoining the ankle and the metatarsophalangeal joint centres and the horizontal plane"* while the plant angle was defined as, *"the angle between the vector adjoining the hip and ankle joint centres and the vertical plane at front foot impact"* (Worthington, King and Ranson, 2013; page 79).

Worthington, King and Ranson (2013) proposed that the knee angle at front foot placement actually contributes to ball release speed by enabling the bowlers to efficiently slow the linear velocity of the pelvis and thereby driving the lower trunk forward about the pelvis. This quickly propels the ball forward (Worthington, King and Ranson, 2013). Feros, Young and O'Brien (2019) agreed with this notion as they said that extending the knee increases angular momentum about the pelvis. There were however, other researchers who found a negative correlation between front knee extension and ball release speed (Glazier, Paradisis and Cooper, 2000; Savage and Portus, 2002).

Some authors have categorised front knee actions into three categories depending on the extent of knee extension involved during front foot strike and have shown that these different categories contribute differently to ball release speed (Loram *et al.*, 2005; Liebenberg, During and Spell, 2010; Worthington, King and Ranson, 2013; Thander, 2023). The first category was the straight leg technique, where the bowlers fully extended their front knee or almost fully upon landing at front foot strike and kept it extended for most of the time, or even up to ball release. This technique was thought to produce high ball release speeds by making the lower body more stable and offering a longer distance between the front foot on the ground and the point of contact with the ball. This produces a greater tangential velocity and makes the technique the most effective at contributing to high ball release speed (Worthington, King and Ranson, 2013).

A second category is one in which bowlers flex their knee at front foot placement and maintain flexion or further flex it before ball release. This technique was shown to reduce ground reaction forces experienced at front foot strike but the lack of extension leads to lower ball release speeds (Worthington, King and Ranson, 2013; Thander, 2023).

The third type of knee action was one in which bowlers landed with a slightly flexed knee and then later extended it into an almost straight knee or fully extended knee (Worthington, King and Ranson, 2013; Thander, 2023). This knee action was considered as the optimum method of front knee action (Worthington, King and Ranson, 2013; Glazier and Wheat, 2014; Thiagarajan *et al.*, 2015; Middleton *et al.*, 2016). This method generated high ball release speeds by providing a lever which makes it easier for the body to rotate and generate high ball release speeds (Glazier and Wheat, 2014; Thiagarajan *et al.*, 2015; Olivier, Olivier and Mnguni, 2022). The advantage of the third type is two-fold, first the knee flexion assists with force attenuation which is then combined with the advantage of an effective lever afforded by the extended knee (Thander, 2023). Olivier, Olivier and Mnguni (2022) also point out that landing with a slightly flexed knee is associated with a more stable trunk and can still generate high ball release speeds while avoiding injury associated with landing with an extended knee. Although this type of knee action is considered as the optimum action, it is not seen quite often in players (Glazier and Wheat, 2014; Middleton *et al.*, 2016). Middleton (2011) postulated that this knee action aids with reducing the effect of ground reaction forces on the body while maintaining the angular momentum. Olivier; Stewart; Green; McKinon (2013) also noted that bowlers who belonged to the flexor-extender group had more bowling accuracy. Although this type of knee action is considered as the optimum action, it is not seen quite often in players (Middleton, 2011; Olivier; Stewart; Green; McKinon, 2013; Glazier and Wheat, 2014; Middleton *et al.*, 2016).

2.4.4.6 Dominant knee flexion (back knee)

Although most research looked at the contribution of front knee kinematics to ball release speeds, some authors also assessed the contribution of the back foot placement. Phillips (2011) showed that there was a positive correlation between back foot knee flexion at back foot placement and ball release speed in both junior and national cricket players. However, in a study by Middleton *et al.* (2016), it was shown that there was no correlation between knee flexion at back foot placement and ball release speeds. Middleton *et al.* (2016) postulated that the contribution that knee flexion at back foot placement makes to ball release speed remains unclear. Phillips (2011) also stated this in their study but suggested that it could have a role in the deceleration of the body.

2.5 Conclusion

This chapter is a literature review of research that looks at factors associated with high ball release speeds. It outlines the findings of previous studies that looked at the roles of different anthropometric and biomechanical factors that contribute to high ball release speeds. In the next chapter, the methods used to carry out this research will be explored.

CHAPTER 3: METHODOLOGY

3.1 Study Design

A retrospective cross-sectional analytical study involving secondary data was conducted. Secondary data taken from bowling biomechanics reports which were compiled during a primary study conducted between 2018 and 2020 were analysed. Some players were tested in 2019 while others were tested in 2020.

3.2 Participants

3.2.1 Source of Participants

The biomechanical reports of elite pace bowlers playing at professional and semi-professional level in South Africa were used in this analysis. The main study from which the bowling biomechanics reports were taken was conducted at the cricket nets of Cricket South Africa Centre of Excellence in Pretoria. This setting allowed for the capturing of the performance of the cricket players in a situation that closely mimics the match setting as much as possible. The secondary study involved analysis of already existing data (bowling biomechanics reports) and no collection of new data.

3.2.2 Sample Selection

Inclusion criteria

The biomechanics reports of male and female bowlers classified as pace bowlers by their technical teams/coaches, aged 18 and above playing at professional and semi-professional level were included in the analysis.

Exclusion criteria

The biomechanics reports of pace bowlers who had injuries were excluded from the analysis.

3.3 Variables

Dependent variable

Ball release speed is the dependent variable and was measured using a Stalker radar gun in km/hr. The bowlers were classified according to speed as follows:

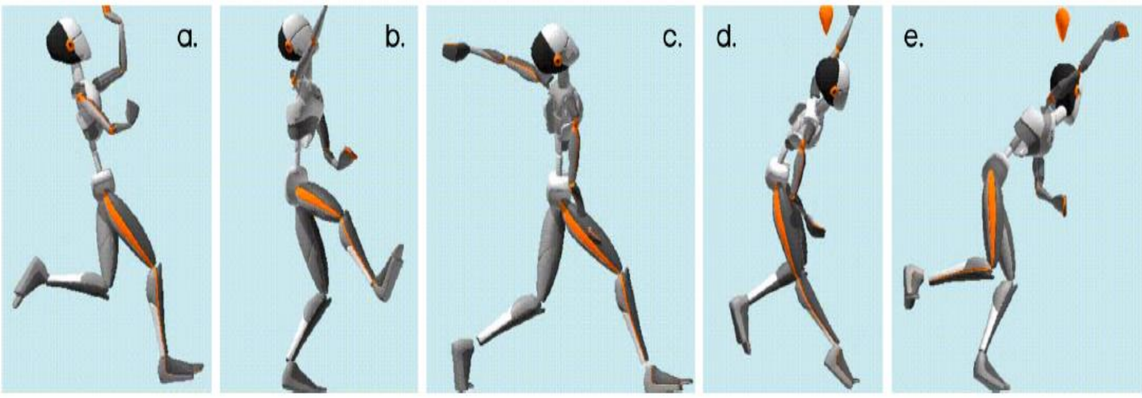
- Medium bowlers – “bowlers with a medium pace of ball release speeds between 120 and 129km/h”.
- Medium-fast bowlers – “bowlers who bowl with a medium fast pace of 130 – 139km/h”.
- Fast bowlers – “bowlers who bowl with a fast pace of greater than 140km/h. (Frost and Chalmers, 2012; Olivier *et al.*, 2016).

Independent variables

The following variables are independent variables and were collected from the biomechanical reports: age, sex, height, mass, BMI, trunk side flexion, trunk rotation, hip flexion and extension, knee flexion and extension, and accuracy. (See Table 3.1).

Biomechanical variables were collected during the different stages of the bowling action which are:

- Back foot contact: “the first frame in which the transverse plane alignment of the back foot could be deemed as stable (due to firm contact with the ground)”.
- Front foot contact: “the first frame when the front (non-dominant) toe marker reached its lowest vertical position” (Olivier *et al.*, 2016; page 78).
- One step after ball release: “the first frame in which the transverse plane alignment of the foot opposite to the front foot could be deemed as stable (due to firm contact with the ground)”.



a. before back foot contact, b. back foot contact, c. front foot contact, d. ball release, e. one step after ball release

Figure 3.1 Stages of the bowling action as shown on the Xsens software (Jacobs *et al.*, 2024)

Table 3. 3: Variables investigated in this study

Variable	Definition
Sociodemographic	
Age (years)	“The part of life from birth to a given time. It is calculated from the date of birth to the current date” (Merriam-Webster.com).
Mass (kg)	“The property of a body that is a measure of its inertia and that is commonly taken as a measure of the amount of material it contains and causes it to have weight in a gravitational field (Merriam-Webster.com)”.
Height (m)	“The distance from the bottom to the top of someone standing upright”. (Merriam-Webster.com)
Body mass index (BMI)	“A measure of body fat that is the ratio of the weight of the body in kilograms to the square of its height in square meters”. (Merriam-Webster.com).
Sex	“The state of being male or female (Merriam-Webster.com).
Biomechanical variables	
Trunk side flexion (degrees)	“The biomechanical variable represents the lateral bending of the trunk. The trunk is the segment between the shoulders (C7 or T1) and L5. Trunk side-flexion to the left was captured as negative degrees, and to the right, it was positive” (Jacobs *et al.*, 2024; page 3).
Trunk rotation (degrees)	“The axial turning of the trunk relative to the pelvis. The trunk is defined as the segment between the shoulders (C7 or T1) and L5, and this rotation is also referred to as the pelvis shoulder separation angle” (Jacobs *et al.*, 2024; page 3).
Pelvis rotation (degrees)	“The rotational movement of the pelvis relative to the lower back (L5)” (Jacobs *et al.*, 2024; page 3).
Hip flexion/extension (degrees)	“The biomechanical movements of the hip joint that involve a decrease (flexion) or an increase (extension)” (Jacobs *et al.*, 2024; page 3).
Knee flexion/ extension (degrees)	“The biomechanical movements of the knee joint that involve a decrease (flexion) or an increase (extension)” (Jacobs *et al.*, 2024; page 3).

Accuracy (score)	"Accuracy was measured using a target behind the stumps based on the target used by Cricket Australia".

3.4 Procedure

3.4.1 Main study

The main study was conducted by the University of Witwatersrand Cricket Hub. The biomechanical analysis of the fast bowlers formed part of Cricket South Africa's service offering towards their Elite Fast Bowling Group. All fast bowlers gave written informed consent for their data to be used in the research project.

The XSens inertial sensor motion analysis system (MVN Link Biomech system; Xsens Technologies B.V., Enschede, The Netherlands) was used to record the bowling techniques of elite female and male pace bowlers. The Xsens captures at a high speed of 240 frames per second which makes it fit for recording fast bowling action. It consists of 17 motion trackers that measure movement at a rate of 240Hz. During collection of the original data, each participant was instructed to warm up in their own accustomed manner and after a calibration process, to bowl six deliveries. Kinematic variables namely shoulder, trunk, pelvis, hip, knee, and ankle angles were continuously calculated throughout each functional movement. All six deliveries for each variable were entered into the analysis. Joint angles at specific times of the bowling action were measured namely back foot contact, front foot contact, ball release and follow through.

Ball release speed was measured using a hand-held radar speed gun (Stalker ATS, Texas). The gun was placed approximately 5 meters from the point of ball release as close to the upper limb's trajectory as possible. The average ball release speed was used for analysis. Accuracy was measured using a target behind the stumps based on the target used by Cricket Australia. An increased score is equal to an increased accuracy, with the maximum score being 100. The target used was a black cloth with scoring zones sewn in white and a red horizontal line 50 centimeters off the ground. 100 points was scored if the ball hit the target on the zone of the off-stump, 50 and 25 points in adjacent zones and zero points if the target was missed altogether (figure 3.1).

Figure 3.2: Accuracy target and hand-held radar gun Olivier, Olivier and Mnguni (2022)

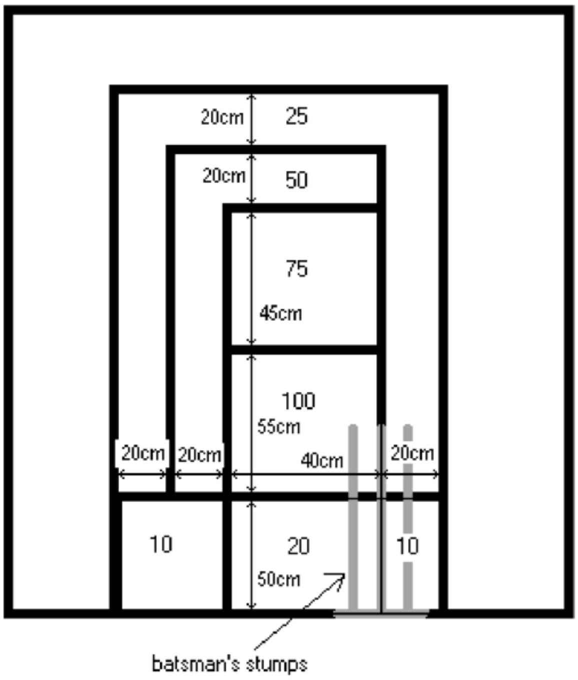


Figure 3.3: Dimensions of the accuracy target based on the work by Elliott, Plunkett and Alderson (2005)

3.4.2 Secondary analysis

The data were extracted from the original reports into Microsoft Excel by my supervisor, Prof Benita Olivier, who was part of the team working on the main study. Data cleaning was done by both of us. Thereafter, I carried out a secondary analysis of the data. No new data were collected as part of this study.

3.5 Ethical Considerations

Ethical clearance for the main study was obtained from the University of Witwatersrand's Human Research Ethics Committee (Medical) with the protocol number M170726. An application for an amendment was submitted to the University of Witwatersrand’s Human Research Ethics Committee (Medical) to add myself as a student and co-investigator onto this project and approval was given with the number M210990.

3.6 Data Analysis

I carried out data analysis using SPSS Version 27 (IBM USA). Normality of the data was explored using the Shapiro Wilk’s test. Data which was found to be normally distributed was age, weight, height and BMI, trunk side flexion and rotation, pelvis rotation, non-dominant hip flexion, dominant hip flexion, dominant knee flexion at back foot placement, non-dominant knee flexion and dominant knee flexion at front foot placement as well as trunk side-flexion one step after ball release, non-dominant hip flexion and dominant knee flexion one step after ball release. Ball release speed (BRS), non-dominant knee flexion at back foot placement, non-dominant hip flexion and dominant hip flexion at front foot placement, trunk rotation and pelvis rotation one step after ball release, dominant hip flexion one step after ball release were positively skewed. Trunk side flexion, trunk rotation, pelvis rotation at front foot placement, and non-dominant knee flexion one step after ball release were negatively skewed.

Descriptive data was presented through measures of central tendency and variance: means and standard deviations (parametric data), and medians and ranges (non-parametric data). The correlation between socio-demographic variables and biomechanical variables and ball release speed was calculated using Spearman’s correlation. Spearman’s correlation ranges from +1, 0 and -1, where a value of -1 is interpreted as a perfect negative correlation, 0 is no correlation and +1 is a positive correlation. The closer the value is to 1, the stronger the correlation is and the strength of the correlation was described as very weak (0.00-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79) and very strong (0.80-1.0). Effect sizes were calculated for parametric and non-parametric data as appropriate (Pautz, Olivier and Steyn, 2018a, 2018b).

Data collected in 2019 and 2020 were presented both separately as well as together. This was done because data collected in 2019 were collected under normal conditions before the lockdown period brought on by the COVID-19 pandemic whereas the data collected in 2020 data were collected at the time when players could return to play albeit with restrictions in place. The data were presented separately so that the reader could have the freedom to interpret the data as such. It is beyond the scope of this study to compare the data before and after the COVID-19 restrictions, although these effects are alluded to where relevant. Any missing data were not replaced.

The objectives of the study and the statistical analysis used to fulfill them is shown in Table 3.2.

Table 3. 4: Objectives of the study and statistical analysis used to fulfill them

Objective	Variables and type of data	Statistical analysis
To determine sociodemographic characteristics associated with high ball release speeds among elite pace bowlers.	Age – ratio Height – ratio Weight – ratio Sex – nominal BMI – ratio	Pearson's (parametric) or Spearman's (non-parametric) correlation coefficients between ball release speed and continuous sociodemographic variables
To determine the biomechanical factors associated with high ball	The following variables are continuous: Trunk side flexion	Pearson or Spearman's correlation coefficients between ball release speed

release speeds among elite pace bowlers.	Trunk rotation Pelvis rotation Centre of mass Hip flexion/extension. Knee flexion/extension Ankle dorsi/plantarflexion Shoulder counterrotation	and continuous biomechanical variables

3.9 Conclusion

This chapter outlines the methods used to analyse data in this study. A secondary data analysis of biomechanics reports was carried out using SPSS version 27. Shapiro Wilk's test was used to assess for normality of the data and the appropriate measures of central tendencies used for the data. Spearman's correlation coefficient was used to highlight the correlation between the different variables and ball release speed. The following chapter is a presentation of the results of the study.

CHAPTER 4: RESULTS

4.1 Introduction

In this chapter, the results of the study will be presented for the group as a whole (combined), as well as for the testing that was done in 2019 and 2020 separately due to the potential influence of reduced training and matches during the COVID-19 lockdown. Comparing the biomechanical outcomes between the two year groups was beyond the scope of this study and is therefore not presented as part of this research report.

4.2 Age, sex and anthropometric factors associated with ball release speed.

The bowling analysis reports of 53 elite pace bowlers were included in this study. The majority of the players (n=35, 66%) were male for the combined group, of which 15 out of the 23 (65.2%) players tested in 2019 were male and 20 of the 30 (66.7%) players tested in 2020 were male (Table 4.1).

The mean ball release speed for male pace bowlers was 128.2 km/h for the combined years, 124.6 ± 6.9 km/h for 2019 and 130.6 ± 8.3 km/h in 2020. The mean ball release speed for female pace bowlers was 95.2 km/h for the combined years, 98.5 km/h in 2019 and 89.7 km/h in 2020 (Table 4.1).

Overall, players were between 18 and 31 years old with a mean age of 24.4 (S.D 3.9) years. The age and anthropometric variables are shown in Table 4.1.

Table 4. 2: Age and anthropometric variables of the male and female pace bowlers (n= 53).

	Combined			2019			2020		
Variable	**Mean**	**S.D.**	**Range**	**Mean**	**S.D.**	**Range**	**Mean**	**S. D.**	**Range**
Age (years)	24.4	3.9	18.0-31.0	23.8	4.4	19.0-30.0	24.7	3.5	18.0-30.0
Mass (kg)	75.4	14.4	49.0-110.0	74.4	13.6	49.0-97.5	77.2	14.4	50.0-110.0
Height (m)	1.8	0.12	1.5-2.1	1.8	0.1	1.5-2.0	1.8	0.1	1.6-2.1
BMI (kg/m^2)	23.5	4.6	19.2-34.7	24.6	2.8	19.2-29.6	22.9	5.2	19.4-34.7

S.D - Standard Deviation; BMI- Body Mass Index, BRS- Ball release speed

The mean age of male pace bowlers in both years was 24.1 years, in 2019 it was 22.3 years and in 2020 it was 25.1 years. The mean age of female pace bowlers in both years combined was 24.8, 24.0 in 2019 and 24.0 years in 2020. The age and anthropometric variables of male and female pace bowlers is shown in Table 4.2.

Table 4.2: Age and anthropometric variables of male and female pace bowlers (n=53)

	Combined				2019				2020			
	Males (n=35)		Females (n=18)		Males (n=15)		Females (n=8)		Males (n=20)		Females (n=10)	
Variable	**Mean (S.D)**	**Range**	**Mean (S.D)**	**Range**	**Mean (S.D)**	**Range**	**Mean (S.D)**	**Range**	**Mean (S.D)**	**Range**	**Mean (S.D)**	**Range**
Age (years)	24.1 (0.3)	18.0 –31.0	24.8 (3.8)	19.0–30.0	22.3 (4.0)	19.0–30.0	24.0 (3.2)	21.0-29.0	25.1 (3.6)	18.0–31.0	24.0 (3.2)	21.0–29.0
Height (m)	1.9 (0.1)	1.7–2.1	1.6 (0.1)	1.5–1.8	1.8 (0.1)	1.7-2.0	1.6 (0.1)	1.6–1.8	1.9 (0.1)	1.7–2.1	1.6 (0.1)	1.6–1.8
Mass (kg)	84.0 (10.4)	58.0–110.0	61.9 (7.8)	49.0–73.0	83.2 (9.7)	66.0–97.5	61.3 (7.6)	50.0–73.0	84.6 (10.1)	58.0–110.0	61.3 (7.6)	50.0–73. 8
BMI (kg/m²)	23.9 (5.0)	19.2–34.7	22.5 (2.3)	19.4–27.5	24.6 (2.8)	19.2–29.6	22.3 (2.6)	20.0–27.5	23.4 (2.1)	19.4-34.7	22.3 (2.6)	20.1–27.5

S.D - Standard Deviation; BMI- Body Mass Index

In the combined group, there was a negative correlation between age and ball release speed. There was a strong positive correlation between height and ball release speed. There was a weak positive correlation between BMI and ball release speed (Table 4.3). The correlation between age, anthropometric factors and ball release speed are shown in Table 4.3.

Table 4. 3: The correlation between age, anthropometrics and ball release speed.

	Combined		**2019**		**2020**	
	BRS		**BRS**		**BRS**	
Variable	**Correlation with BRS (ρ)**	**p-value**	**Correlation with BRS (ρ)**	**P-value**	**Correlation with BRS (ρ)**	**P-value**
Age (years)	-0.264	0.002	-0.310	0.022	-0.370	0.009
Height (m)	0.724	<0.001	0.534	0.003	0.441	0.002
Mass (kg)	0.589	<0.001	0.230	0.002	0.134	0.009
BMI (kg/m²)	0.212	0.003	0.160	0.002	0.120	0.001

B.R.S- ball release speed

In both years combined, there was a positive correlation between age and ball release speed for female pace bowlers. There was a very weak positive correlation between height and ball release speed for male pace bowlers. There was a weak negative correlation between BMI and ball release speed for male pace bowlers but a moderate positive correlation between BMI and ball release speed for female pace bowlers in both years combined (Table 4.4).

Table 4.4: Correlation between age, anthropometric characteristics and ball release speed in male and female pace bowlers (n=53).

	Combined		**2019**		**2020**	
	BRS Male (n=35)	**BRS Female (n=18)**	**BRS Male (n=15)**	**BRS Female (n=8)**	**BRS Male (n=20)**	**BRS Female (n=10)**
	Spearman's ρ (p-value)	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
Age (years)	-0.114 (0.193)	**0.353 (0.005)**	-0.310 (0.032)	0.626 (0.009)	-0.210 (0.054)	0.254 (0.092)
Height (m)	**0.256 (0.002)**	0.035 (0.775)	-0.121 (0.371)	0.201 (0.236)	0.326 (0.002)	0.282 (0.042)
Mass (kg)	-0.042 (0.627)	0.230 (0.077)	-0.320 (0.015)	-0.280 (0.294)	0.010 (0.932)	0.420 (0.005)
BMI (kg/m^2)	-0.248 (0.004)	**0.441 (<0.001)**	-0.202 (0.131)	0.600 (0.014)	-0.216 (0.056)	0.606 (<0.001)

BMI- Body mass index; BRS- ball release speed

4.3 Biomechanical factors associated with ball release speed

4.3.1 Trunk side flexion

The median trunk side flexion for male pace bowlers was -2.8º and 2.8º for females at back foot placement, 0.8º for male pace bowlers and -4.5º for female pace bowlers at front foot placement while one step after ball release speed it was 1.7º for male pace bowlers and 6.7º for female pace bowlers. The median and ranges of trunk side flexion are shown in Table 4.5.

Table 4.5: Trunk side flexion of the male and female pace bowlers (n=53)

	Trunk Side Flexion (°)											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
BFP	-2.8	-23.1-26.6	2.8	-16.9-10.0	16.9	-12.7 -33.1	2.7	-16.9-10.0	-0.4	-20.6 -26.6	2.8	-4.2-9.7
FFP	0.8	-28.6-33.2	-4.5	- 28.6-31.6	19.3	-12.7 -33.2	-0.9	-20.7--11.7	-3.8	-28.6 -31.6	-5.8	-14.7-2.9
One Step After FFP	1.7	-34.5 -47.1	6.7	-34.5-33.9	15.4	-17.7 -33.8	12.5	-7.1 -33.8	9.4	-34.5-47.1	7.8	-32.9-33.9

BFP- Back Foot Placement FFP- Front Foot Placement

In both years combined, there was a weak positive correlation between trunk side flexion at back foot placement as well as a weak positive correlation between trunk side flexion at front foot placement and ball release speed for female pace bowlers (Table 4.6).

Table 4.6: The correlation between trunk side flexion and ball release speed (n=53)

	Trunk Side Flexion (º)					
	Combined		**2019**		**2020**	
	Male (n=35)	**Female (n=18)**	**Male (n=15)**	**Female (n=8)**	**Male (n=20)**	**Female (n=10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	**0.289 (<0.001)**	-0.196 (0.110)	0.272 (0.041)	-0.564 (0.023)	-0.207 (0.057)	-0.140 (0.323)
BRS at FFP	-0.186 (0.027)	**0.173 (0.159)**	-0.408 (0.002)	0.047 (0.863)	0.228 (0.036)	-0.050 (0.726)
BRS at One step after FFP	-0.040 (0.639)	-0.125 (0.318)	-0.183 (0.176)	-0.883 (<0.001)	-0.128 (0.253)	0.063 (0.661)

FFP- Front Foot Placement, BFP- Back Foot Placement, B.R.S- ball release speed

4.3.2 Trunk Rotation

The median trunk rotation for male pace bowlers was -3.4° and 6.7° for female pace bowlers at back foot placement, 0.5° for male pace bowlers and -4.5º for female pace bowlers at front foot placement whereas one step after ball release speed it was 1.7° for male pace bowlers and for 21.0° female pace bowlers. Table 4.7 below outlines the medians and ranges of trunk rotation.

Table 4.7 Trunk rotation of the male and female pace bowlers (n=53)

	Trunk Rotation (º)											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
BRS at BFP	-3.4	-34.1-62.7	6.7	-18.2-39.0	25.6	-24.9-55.8	7.5	-18.2-31.1	8.1	-32.8-62.7	5.4	-10.7-38.9
BRS at FFP	0.5	-21.7-52.8	-4.5	-20.7-11.7	19.3	-12.7 -33.2	6.7	-20.7-33.2	-3.8	-28.6-31.6	-21.8	-43.0-34.5
BRS at One Step After FFP	1.7	-34.5-47.1	21.0	-53.2-56.7	29.2	-22.2 -56.7	1.6	-27.3-30.8	24.7	-53.2 -56.7	22.6	-47.1-56.7

BRS- Ball release speed BFP- Back Foot Placement FFP- Front Foot Placement

Table 4. 8: The correlation between trunk rotation and ball release speed (n=53)

	Trunk Rotation (°)					
	Combined		**2019**		**2020**	
	Male (n=35)	**Female (n=18)**	**Male (n =15)**	**Female (n=8)**	**Male (n=20)**	**Female (n=10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	0.042 (0.623)	0.070 (0.570)	0.349 (0.008)	0.169 (0.531)	-0.472 (<0.001)	-0.140 (0.323)
BRS at FFP	-0.063 (0.461)	0.135 (0.271)	-0.272 (0.041)	0.830 (<0.001)	0.282 (0.009)	0.162 (0.250)
BRS at One step after	-0.086 (0.318)	-0.161 (0.197)	-0.149 (0.273)	-0.254 (0.343)	-0.463 (<0.001)	-0.113 (0.436)

BFP- Back Foot Placement, BRS- Ball release speed, FFP- Front Foot Placement

4.3.3 Pelvis rotation

The median pelvis rotation for males was 5.5° and 3.5° for female pace bowlers at back foot placement, 0.5º for male pace bowlers and -4.5° for female pace bowlers at front foot placement and 1.7° for male pace bowlers and 11.1° for female pace bowlers one step after ball release speed (Table 4.9). The medians and ranges of pelvis rotation are outlined in Table 4.9.

Table 4.9: Pelvis rotation of the pace bowlers

	Pelvis Rotation											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
BRS at BFP (°)	5.5	-14.8-48.3	3.5	-7.3-17.5	7.8	-11.1-48.3	3.7	-7.3-14.2	3.4	-14.8-28.0	2.44	-4.7-17.5
BRS at FFP (°)	0.5	-28.6-33.2	-4.5	-7.3-11.7	-5.3	-15.1-17.7	-9.2	-12.2-9.6	-4.6	-22.0-27.0	-5.9	-22.0-28.0
BRS at One Step After FFP (°)	1.7	-34.5-47.1	11.1	-23.8-26.4	13.6	-10.5-25.6	**	**	11.4	-23.8-25.6	13.0	-10.5-25.6

BFP- Back Foot Placement, BRS- Ball release speed, FFP- Front Foot Placement. **Pelvis rotation data for females tested in 2019 was missing

For both years combined, a weak positive correlation between pelvis rotation at front foot placement for male pace bowlers and a very weak positive correlation for female pace bowlers (Table 4.10).

Table 4.10: The correlation between pelvis rotation and ball release speed

Pelvis Rotation (°)						
	Combined		**2019**		**2020**	
	Male (n=35)	**Female (n=18)**	**Male (n=15)**	**Female (n=8)**	**Male (n=20)**	**Female (n=10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	-0.396 (<0.001)	-0.019 (0.876)	-0.181 (0.181)	-0.138 (0.623)	-0.464 (<0.001)	-0.145 (0.304)
BRS at FFP	**0.357 (<0.001)**	**0.180 (0.146)**	0.473 (<0.001)	0.432 (0.108)	0.284 (0.009)	0.034 (0.813)
BRS at One step after FFP	-0.418 (<0.001)	-0.179 (0.146)	-0.553 (<0.001)	**	-0.429 (<0.001)	-0.154 (0.279)

BFP- Back Foot Placement, BRS- ball release speed, FFP- Front Foot Placement.

**Pelvis rotation data for females tested in 2019 was missing

4.3.4 Non-dominant side hip flexion

In the combined group, the median non-dominant hip flexion for male pace bowlers was 51.3° and for female pace bowlers was 51.5° at back foot placement, 0.5° for male pace bowlers and 43.6° for female pace bowlers at front foot placement then 1.7º for male pace bowlers and 23.1º for female pace bowlers one step after ball release speed. The medians and ranges of non-dominant hip flexion are outlined in Table 4.11.

Table 4.11: Non-dominant side hip flexion of the pace bowlers (n=53)

	Hip Flexion (°)											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
BRS at BFP	51.3	12.2-90	51.5	10.7-84.2	52.7	29.5-83.5	-3.0	-23.1-11.4	51.0	12.2.-90.5	51.4	10.7 - 84.2
BRS at FFP	0.5	-28.6-33.2	43.6	-38.6 - 72.0	46.6	16.0-72.0	47.6	-26.1-67.1	43.7	-38.6 - 72.0	47.1	16.0 - 72.0
BRS at One Step After FFP	1.7	-34.5-47.1	23.1	-38.6-82.8	18.4	-25.8-67.9	29.5	19.0-43.7	18.5	-25.8 - 67.9	18.5	-25.8 - 67.9

BRS- Ball release speed BFP- Back Foot Placement FFP- Front Foot Placement

In both years combined, there was a very weak positive correlation between non-dominant hip flexion at front foot placement and ball release speed for both male and female pace bowlers. There was a moderate positive correlation between non-dominant hip flexion one step after ball release and ball release speed for female pace bowlers (Table 4.12).

Table 4.12: Correlation between non-dominant hip flexion and ball release speed (n= 53)

	Hip Flexion					
	Combined		**2019**		**2020**	
	Male (n=35)	**Female (n=18)**	**Male (n=15)**	**Female (n=8)**	**Male (n=20)**	**Female (n=10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	-0.375 (<0.001)	0.089 (0.473)	-0.412 (0.002)	0.351 (0.200)	-0.416 (<0.001)	-0.125 (<0.001)
BRS at FFP	**0.132 (0.120)**	**0.240 (0.050)**	0.216 (0.107)	0.545 (0.029)	0.065 (0.556)	0.327 (0.019)
BRS at One step after FFP	0.078 (0.364)	**0.464 (<0.001)**	-0.019 (0.893)	0.739 (0.001)	-0.007 (0.950)	-0.061 (0.069)

BRS – ball release speed, FFP- Front Foot Placement, BFP- Back Foot Placement

4.3.5 Dominant side hip flexion

The median dominant hip flexion for male pace bowlers was 19.6° and 17.0° for female pace bowlers at back foot placement, 0.5° for male pace bowlers and 3.4° for female pace bowlers at front foot placement and 1.7° for male pace bowlers and 63.4° for female pace bowlers one step after ball release. The median and ranges of dominant hip flexion are shown in Table 4.13.

Table 4. 13: Dominant side hip flexion of the pace bowlers (n= 53)

	Hip flexion (°)											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
BRS at BFP	19.6	-7.5 - 54.2	17.0	-7.5-54.2	21.2	8.3-54.2	-3.0	-23.1-11.4	18.1	-7.5-42.2	18.3	-7.5 - 42.2
BRS at FFP	0.5	-28.6-33.2	3.4	-18.3-81.0	-1.5	-12.7 - 33.2	-1.6	-8.0-14.1	-1.3	-18.3-81.0	-1.6	-18.3-81.0
BRS at One Step After FFP	1.7	-34.5-47.1	63.4	-3.4-101.4	62.8	-18.9 - 78.3	72.0	-52.5-82.1	9.4	-34.5 - 47.1	63.4	-3.4-85.4

BFP- Back Foot Placement FFP- Front Foot Placement

For both years combined, there was a weak positive correlation between dominant side hip flexion at front foot placement and ball release speed for male pace bowlers (Table 4.14).

Table 4.14: The correlation between dominant side hip flexion and ball release speed (n=53)

	Hip Flexion					
	Combined		**2019**		**2020**	
	Male (n=35)	**Female (n=18)**	**Male (n=15)**	**Female (n=8)**	**Male (n=20)**	**Female (n=10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	-0.169 (0.047)	-0.004 (0.977) checked	-0.183 (0.176)	0.769 (<0.001) done	-0.015 (0.894)	-0.061 (0.669) checked
BRS at FFP	**0.258 (0.002)**	-0.128 (0.767)	0.271 (0.041)	0.028 (0.917)	0.028 (0.803)	0.425 (0.002)
BRS at One step after	0.093 (0.283)	0.039 (0.758)	0.303 (0.023)	0.523 (0.038)	-0.017 (0.882)	0.039 (0.791)

FFP- Front Foot Placement, BFP- Back Foot Placement

4.3.6 Non-dominant side knee flexion

The median non-dominant knee flexion for male pace bowlers was 38.0° and 37.6° for female pace bowlers at back foot placement, 0.5° for male pace bowlers and 13.9° for female pace bowlers at front foot placement while one step after ball release speed it was 1.7° for male pace bowlers and 31.4° for female pace bowlers. The medians and ranges of dominant knee flexion are shown in Table 4.15.

Table 4.15: Non-dominant knee flexion for the participants

	Knee Flexion											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
BRS at BFP (°)	38.0	-8.1 - 97.1	37.6	-8.1-104.8	40.6	-5.5-97.1	-3.0	-23.1-11.4	36.8	-8.1-95.2	31.2	-8.1 - 70.0
BRS at FFP (°)	0.5	-28.6 - 33.2	13.9	-15.8-51.6	14.5	-0.5-45.2	19.5	-8.3-34.9	12.9	-13.2-45.2	15.2	-0.5 - 45.2
BRS at One Step After FFP (°)	1.7	-34.5 - 47.1	31.4	-3.8-141.9	27.3	2.9 - 128.4	22.7	-0.7-56.0	31.9	2.9-128.4	27.0	2.9-128.4

BFP- Back Foot Placement FFP- Front Foot Placement

In both years combined, there was a weak negative correlation between non-dominant knee flexion at back foot placement for both male and female pace bowlers. There was a weak positive correlation between non-dominant knee flexion at front foot placement and ball release speed for both male and female pace bowlers.

Table 4. 16: Correlation between non-dominant side knee flexion and ball release speed (n=53)

	Knee Flexion					
	Combined		**2019**		**2020**	
	Males (n= 35)	**Females (n=18)**	**Males (n= 15)**	**Females (n=8)**	**Males (n= 20)**	**Females (n= 10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	**-0.283 (<0.001)**	**-0.245 (0.049)**	0.015 (0.911)	-0.811 (<0.001)	-0.422 (<0.001)	0.022 (0.881)
BRS at FFP	**0.203 (0.016)**	**0.182 (0.140)**	0.110 (0.416)	0.554 (0.026)	0.112 (0.312)	0.188 (0.186)
BRS at One step after	0.123 (0.154)	0.070 (0.580)	0.119 (0.378)	-0.893 (<0.001)	0.272 (0.015)	0.009 (0.951)

BFP- Back Foot Placement, BRS – Ball release speed, FFP- Front Foot Placement

4.3.7 Dominant side knee flexion

The median dominant knee flexion for male pace bowlers was 36.1° and 34.2° for females at back foot placement, 0.5° for male pace bowlers 50.0° for female pace bowlers at front foot placement and 1.7° for male pace bowlers and 35.3° for female pace bowlers one step after ball release. The medians and ranges of dominant side knee flexion are shown in Table 4.17 below.

Table 4.17 Dominant side knee flexion for the participants (n=53).

	Knee Flexion											
	Combined				2019				2020			
	Male (n=35)		Female (n= 18)		Male (n=15)		Female (n=8)		Male (n=20)		Female (n=10)	
Time Stamp	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
BRS at BFP	36.1	-42.1 - 124.3	34.2	7.4-124.3	38.3	15.0-72.6	-3.0	-23.1-11.4	35.1	-42.1-124.3	37.1	11.6-124.3
BRS at FFP	0.5	-28.6 - 33.2	50.0	18.0-125.8	51.4	20.1-125.8	45.6	26.9-59.4	-3.8	-28.6-31.6	51.4	20.1-125.8
BRS at One Step After FFP	1.7	-34.5 - 47.1	35.3	-43.5 - 136.3	38.8	10.9-136.3	37.5	18.6-52.0	38.7	-43.5-136.3	39.0	17.7-136.3

BFP- Back Foot Placement FFP- Front Foot Placement

For both years combined, there was a very weak positive correlation between non-dominant knee flexion at back foot placement for male pace bowlers and a weak positive correlation between dominant knee flexion at back foot contact for female pace bowlers. There was a weak positive correlation between dominant knee flexion one step after ball release and ball release speed for both male and female pace bowlers (Table 4.18).

Table 4. 18: Correlation between dominant side knee flexion and ball release speed

	Knee Flexion					
	Combined		**2019**		**2020**	
	Male (n= 35)	**Female (n=18)**	**Male (n=20)**	**Female (n= 8)**	**Male (n= 20)**	**Female (n= 10)**
Time Stamp	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**	**Spearman's ρ (p-value)**
BRS at BFP	**0.130 (0.126)**	**0.243 (0.046)**	0.241 (0.074)	0.834 (<0.001)	0.161 (0.144)	0.328 (0.021)
BRS at FFP	0.161 (0.060)	0.008 (0.951)	0.137 (0.313)	0.285 (0.285)	0.083 (0.456)	0.342 (0.023)
BRS at One step after FFP	**0.255 (0.003)**	**0.337 (0.006)**	0.018 (0.896)	0.028 (0.917)	0.290 (0.008)	0.471 (<0.001)

BFP- Back Foot Placement, BRS- ball release speed, FFP- Front Foot Placement

4.6 Conclusion of the results

Our results outline the profile of the pace bowlers and also demonstrate the different anthropometric and biomechanical factors that contribute to fast ball release speeds. The results show differences in the strategies used by male and female pace bowlers in generating high ball release speeds. The next chapter will be a discussion of the results and how they compare to previous studies.

CHAPTER 5: DISCUSSION

5.1 Introduction

This study sought to investigate the age, sex, anthropometric, and biomechanical factors associated with high ball release speeds. The anthropometric factors were height, mass and BMI while the biomechanical factors which we explored were trunk side flexion, trunk rotation, pelvis rotation, hip flexion and knee flexion at front foot placement, back foot placement and one step after ball release. These biomechanical variables were included in this research report as they have been the centre of discussion in previous research (Elliott, Foster and Gray, 1986; Wormgoor, Harden and Mckinon, 2010; Glazier and Wheat, 2014; Felton, Lister, Worthington, 2018). In addition, these are the variables which were highlighted in the biomechanics reports on which this study is based. In this discussion, we will compare the results of this study to those of previous studies and outline any similarities or differences, aiming to explain the reasons for this as well as share insights into the results.

5.2 Age and anthropometric factors associated with ball release speed

The participants in this study were elite pace bowlers. An elite athlete is considered as an athlete who plays a sport at a professional level and receives remuneration for it. The level at which players play is important and the relationship between ball release speed and age, anthropometric and biomechanical factors may differ between these groups. Findings from one population group can therefore not be transferred to another. In our study, a homogenous group of elite players contracted to Cricket South Africa was investigated. Felton, Lister, Worthington, (2018) also investigated male and female elite pace bowlers in their study. The participants in the study by Wormgoor, Harden and Mckinon. (2010) were cricket players who played for clubs in the premier league across Gauteng while the participants in the study by Alderson (2007) were males who played at first grade level or above in the Western Australian Cricket Association competition, that is those who competed in senior inter-club or district cricket competitions. In contrast to our study, Loram *et al.* (2005) looked at ball release speeds in high school players. Phillips (2011) chose to compare three sets of players, i.e junior, emerging and national cricket bowlers in their study. Lyons (2023) investigated high performance female pace bowlers.

Our study included both males and females and this enabled us to analyse the data separately and identify the impact of sex on the ball release speeds as well as on the kinematics at the different stages of the bowling action. By separating male and female pace bowlers, we were able show that they use different strategies to achieve high ball release speeds. Similar to our study, Felton, Lister, Worthington (2018) had both male and female elite pace bowlers and identified that they used different strategies in the generation of high ball release speeds. However, this is in contrast to other studies which only had male bowlers. In the studies by Alderson (2007), Phillips (2011) and Wormgoor, Harden and Mckinon (2010) there were male pace bowlers and Loram *et al.* (2005) looked at high school boys. Lyons (2023) chose to investigate only female pace bowlers in order to confirm whether the factors associated with high ball release speeds in male pace bowlers were comparable to their female counterparts.

5.2.1 Age

The mean age for the males in our study was 24.11 ± 3.9 years and this was comparable to the age of participants in previous studies (Glazier, Paradisis and Cooper, 2000; Alderson *et al.*, 2007; Wormgoor, Harden and Mckinon, 2010). The mean age in the study done by Glazier, Paradisis and Cooper (2000) was 21.0 ± 0.9, 20.9 ± 2.2 for those in the study by Alderson (2007), for those in the study by Wormgoor, Harden and Mckinon (2010) was 22.0 ± 3.0 years and 20.1 ± 2.2 years in the study by Phillips (2011). However, this was in contrast to the study done by Loram *et al.* (2005) who carried out a study with school going boys who had a mean age of 16.6 ± 0.7 years. The mean age for female pace bowlers was 24.8 ± 3.7 years. The participants in the study by Felton, Lister, Worthington (2018) were also slightly younger than ours. Male pace bowlers had a mean age of 20.1 ± 2.6 years while female pace bowlers had a mean age of 19.9 ± 3.2 years. The mean age of the female pace bowlers in the study by Lyons (2023) was 22.3 ± 4.7 years..

Analysis of our data revealed a positive correlation between age and ball release speed (ρ=0.353, p=0.005) for female pace bowlers. The positive correlation between age and ball release speed could be attributed to better bowling techniques which may have been gained through experience that is, assuming that the older pace bowlers started their careers earlier than the younger ones. This information was not available in this study, but the role of coaching and years of experience can be determined in future research.

It is interesting to note that this relationship is not the same for male pace bowlers in our study as there was a negative correlation between age and ball release speed (ρ=-0.114, p=0.193). The age group of the male pace bowlers was 19 to 31 years as compared to females who had an age range of 18 to 30 years. The older male bowlers seem to become slower than the younger bowlers. This is in contrast to past studies which state that older pace bowlers bowl faster than their younger counterparts and attributed it to longer limb lengths as well as a faster angular velocity of the bowling arm (Stockill *et al.*, 1996).

The males in our study had a mean ball release speed of 128.2 ± 8.2 km/h. According to Frost (2012) and Olivier *et al.* (2016) the participants in our study were medium bowlers because they had an average ball release speed of 128.2 ± 8.2 km/h. These values were comparable to the ball release speeds reported in previous studies (Glazier, Paradisis and Cooper, 2000; Wormgoor, Harden and Mckinon, 2010b;

Worthington, 2010; Middleton *et al.*, 2016). The elite pace bowlers in the study by Wormgoor, Harden and Mckinon (2010) had a mean ball release speed of 122.4 ± 4.68km/h while the mean ball release speed for junior bowlers in the study by Phillips (2011) was 120.24 ± 4.32km/h, 123.84 ± 3.24km/h for emerging bowlers and 126 ± 6.84km/h for national bowlers. The bowlers in the study by Worthington, King and Ranson (2013) had a mean of 125.64 ± 6.12 km/h.

The male pace bowlers in our study bowled slightly faster than the bowlers in the studies by Glazier, Paradisis and Cooper (2000), Loram *et al.* (2005) and Alderson (2007). For the study by Glazier, Paradisis and Cooper (2000), the ball release speed was 113.4 ± 6.8km/h while for those in the study by Alderson (2007) it was 116.856 ± 4.5km/h, for Middleton et al., (2009) it was 116.86 ± 4.53 km/h and those in the study by Loram *et al.* (2005) had an average ball release speed of 105.120 ± 6.48km/h. The discrepancy may be because the participants in our study were elite pace bowlers while the bowlers in the study by Loram *et al.* (2005) were high school fast-medium bowlers. Their younger ages (16.6 ± 0.7) may mean that they had less experience and skill than the pace bowlers in our study who had an average age of 24.1 ± 0.3 years hence may have less effective techniques for bowling faster.

According to Glazier, Paradisis and Cooper (2000), a study by Stockill and Bartlett (1996) postulated that younger international bowlers had lower ball release speeds than their senior counterparts because the older bowlers had a higher angular velocity due longer upper limb lengths. However, this cannot be inferred in our studies as upper limb measurements were not taken. In contrast to our findings, Glazier, Paradisis and Cooper (2000) reported that elite level fast bowlers deliver the ball between 129km/h and 145.8km/h. They even went on to describe express bowlers who, though rare, can bowl speeds greater than 145.8km/h.

5.2.2 Sex

The literature shows a discrepancy between male pace bowlers and female pace bowlers and shows that male pace bowlers tend to have higher ball release speeds than their female counterparts (Felton, Lister, Worthington, 2018). This is also evidenced in our study where male pace bowlers had a mean ball release speed of 128.2 ± 8.2 m/h while their female counterparts had a mean ball release speed of 91.7± 15.2 km/h. This was comparable to the study by Felton, Lister, Worthington. (2018) which showed that male pace bowlers had a higher ball release speed of 125.64 ± 6.12 km/h as compared to 100.44 ± 5.04 km/h for females. This finding could be because the male pace bowlers in our study had taller statures (1.9 ± 0.08m) than their female counterparts (1.6 ± 0.06m) and therefore had a longer lever on which to pivot and produce greater ball release speeds. However, we cannot rule out that this discrepancy could be because of other factors that were also at play.

The discrepancy in height was also noted by Felton, Lister, Worthington (2018) whose male pace bowlers were also taller (1.88 ± 0.08m) than the female pace bowlers (1.67 ± 0.07m) and they suggest that the shorter torsos and arms possessed by female pace bowlers could pose as a disadvantage for them as long arms have the advantage of increasing the distance between the ball and the body therefore increasing the ball's velocity. However, they suggest that female pace bowlers may have less experience and training as compared to males due to the women's league being started much later than the male league. The lesser ball release speeds in female pace bowlers may also be due to the fact that the coaching practices currently being used are informed from analysis done on male players and may not be yielding the best possible results for female pace bowlers (Felton, Lister, Worthington, 2018). In contrast to our findings, the female pace bowlers in the study by Lyons (2023) had a relatively lower ball release speed of 82.8 ± 6.48 km/h.

5.2.3 Height

Our male participants had a mean height of 1.9 ± 0.08m. According to Johnstone *et al.* (2014), the majority of elite pace bowlers have a height of at least 1.8m. This height also corresponded to the height of 1.83 ± 0.1m in the study by Glazier, Paradisis and Cooper (2000) and to the height of the participants in the study by Alderson (2007) who had a mean height of 1.87 ± 0.063m and a height of 1.83 ± 0.009m shown in results by Wormgoor, Harden and Mckinon (2010). In the study by Felton, Lister, Worthington (2018), male pace bowlers had a mean height of 1.88 ± 0.08m as compared to a mean height of 1.67 ± 0.07m for females and the female pace bowlers in the study by Lyons (2023) had a shorter stature with a mean height of 1.68 ± 0.08m. This was in the same range as our female pace bowlers who had a mean height of 1.6 ± 0.06m.

Previous studies showed a positive correlation between a cricketer's height and ball release speed (Stockill *et al.*, 1996; Glazier, Paradisis and Cooper, 2000; Bartlett *et al.*, 2007; Felton, Lister, Worthington, 2018; Lyons, 2023). Our study also showed a positive correlation between height and ball release speed. However, there was a significant weak correlation between height and ball release speed for male pace bowlers ($\rho=0.256$, $p=0.002$) and a very weak positive correlation ($\rho=0.035$, $p=0.775$) for female pace bowlers. Glazier, Paradisis and Cooper (2000) reported that longer limb lengths, and therefore a taller stature, correlated to ball release speed. It was postulated that bowlers with a taller stature had a longer lever on which to pivot and therefore this increased the velocity. Lyons (2023) who carried out a study which focused on female pace bowlers also agreed with this notion and showed that bowlers with greater heights had higher ball release speeds. However, they cautioned that these two variables did not have a linear relationship and that at some point a plateau would be reached because the longer a limb is, the heavier it would be and therefore, more difficult to move. This means that a player would need to have more muscle power in order to overcome the increase in size and generate ball release speeds as compared to their shorter counterparts (Lyons, 2023).

In contrast to these findings, Loram *et al.* (2005) did not find any correlation between height and ball release speed. This was also evidenced in the study by Wormgoor, Harden and Mckinon (2010) who did not find any advantage in having a taller stature as far as ball release speed is concerned and concluded that longer limbs only had a minor contribution, if any, to ball release speed.

5.2.4 Mass

The mean mass of our male pace bowlers was 84.0 ± 10.4 kg which was in the same range as the participants in previous studies (Glazier, Paradisis and Cooper, 2000; Alderson *et al.*, 2007; Wormgoor, Harden and Mckinon, 2010). The mean mass for pace bowlers in the Glazier, Paradisis and Cooper (2000) was 77.2± 8.1kg, while those for Alderson (2007) had a mean mass of 81.4 + 7.8 kg, and there was a mean mass of 82.0 ± 10.4kg for the participants in the study by Wormgoor, Harden and Mckinon (2010). The male pace bowlers in the study by Felton, Lister, Worthington (2018) had a mean mass of 81.5 ±7.1 kg. The mean mass for female pace bowlers in this study was 61.9 ± 7.8 kg which was in the same range with the values in the study by Felton, Lister, Worthington (2018) whose female pace bowlers had a mean mass of 64.4 ± 8.8 kg. The female pace bowlers in the study by Lyons (2023) who had a mean mass of 73.0 ± 8.3 kg were slightly heavier than our female pace bowlers. Our study showed a positive correlation between mass and ball release speeds for female pace bowlers but a negative correlation between mass and ball release speeds for male pace bowlers. This could be because male pace bowlers were heavier (84.0 ± 10.4 kg) than the female pace bowlers (61.9 ± 7.8 kg).This is in contrast to findings by Phillips (2011) who did not find any correlation between mass and ball release speed.

5.3 Biomechanical factors associated with ball release speed

5.3.1 Trunk side flexion

Male and female pace bowlers in our study seemed to have different strategies when it came to generating ball release speed through trunk side flexion. At back foot placement, male pace bowlers showed a significant weak positive correlation ($\rho=0.289$, $p<0.001$) between trunk side flexion and ball release speed while there was a weak negative correlation ($\rho=-0.196$, $p=0.110$) between trunk side flexion and ball release speed for female pace bowlers. Therefore, at back foot placement, males used more side flexion to generate ball release speeds as opposed to females. This confirmed the findings of Middleton (2011) who found that an increase in trunk side flexion was associated with high ball release speeds. Prasad (2015) postulated that trunk side flexion increased the rotation in the shoulder of the bowling arm and thus increased ball release speed (Prasad, 2015).

At front foot placement, there was a significant weak negative correlation ($\rho=-0.186$, $p=0.027$) between trunk side flexion and ball release speed for male pace bowlers whereas for female pace bowlers there was a weak positive correlation ($\rho=0.173$, $p=0.159$) between trunk side flexion and ball release speed. These results show that males and females use different strategies when it comes to generating faster ball release speeds and therefore it is important to analyse male and female pace bowlers separately. It is also why it is important to create more research in women's cricket. The results for male pace bowlers were similar to those in the study by Alderson (2007) who found a moderate negative correlation between trunk side flexion and ball release speed. Their findings suggested that high ball release speeds were not dependent on trunk side flexion and in order to achieve high ball release speeds, a pace bowler has to reduce the extent to which they bend to the side (Alderson 2007). Thander (2019) also found that in under 19 boys, there was a significant negative correlation between trunk side flexion and ball release speed. One step after ball release speed, both males and females had a negative correlation between ball release speed and trunk side flexion, although this was not statistically significant. This was also in line with the findings by Alderson (2007) who found a negative correlation between trunk side flexion and ball release speed.

5.3.2 Trunk Rotation

It was suggested by Prasad (2015) and Glazier, Paradisis and Cooper (2000) that trunk rotation has a role in the generation of ball release speeds as it rapidly increases the speed of the bowling arm. Our results showed that there was a very weak positive correlation between trunk rotation and ball release speed for both male pace bowlers and female pace bowlers at back foot contact. This was in line with results by Olivier, Stewart, Green, McKinon (2013) who found a positive correlation between trunk rotation to the left (for right handed bowlers).

However, at front foot contact, there is evidence that the strategies used to attain high ball release speeds by males and females are different. There was a weak negative correlation between trunk rotation and ball release speed (ρ=-0,063, p=0.461) for male pace bowlers while for female pace bowlers there was a strong positive correlation between trunk rotation and ball release speed (ρ=0.135, p=0.271). This disparity in male and female pace bowlers was also noted by Letter *et al.* (2022a) and they noted that females tend to use trunk rotation more than their male counterparts. The findings in male pace bowlers are in contrast to the suggestion by Feros, Young and O'Brien (2019) who postulated that bowlers who generate high ball release speeds counter-rotate their trunk more. One step after ball release, both males and females had a negative correlation between trunk rotation and ball release speed.

5.3.3 Pelvis Rotation

In our study, a negative correlation between pelvis rotation and ball release speed exists at back foot placement and one step after front foot placement, with a positive correlation between pelvis rotation and ball release speed at front foot placement. This relationship was the same for both males and females. This is similar to the findings by Glazier and Wheat (2014) who highlighted that a greater pelvic and thoracic rotation is related to higher ball release speeds. A greater range of pelvis rotation enables players to move through a larger arc and thereby contributes to a higher ball release speed (Glazier and Wheat, 2014).

The findings in our study were in contrast to the findings by Felton, Lister, Worthington (2018), who suggested that female pace bowlers tend to rotate their pelvis more than males in order to generate ball release speeds. These findings suggested that male and female pace bowlers have different strategies when it comes to pelvis rotation and the generation of ball release speed.

5.3.4 Hip flexion

5.3.4.1 Non-dominant hip flexion

In the study by Felton, Lister, Worthington (2018) it was shown that females have a greater hip flexion angle than males at back foot placement as males tend to have a more extended hip which enables them to lean back and use more trunk extension during back foot placement. However, this is not the case in our study as both males and females have almost the same hip angle at back foot placement (51.2º for males and 51.5º for females).

In our study, a weak positive correlation exists between non-dominant hip flexion and ball release speed ($\rho=0.089$, $p=0.473$) at back foot placement for female pace bowlers. In contrast to this, male pace bowlers had a weak negative correlation between non-dominant hip flexion and ball release speed as was the case in the study by Felton, Lister, Worthington (2018). At front foot placement, there was a positive correlation between non-dominant hip flexion and ball release speed and this was a strategy used by both male and female pace bowlers. For females, if the years are split up, the correlation becomes stronger. Even though both years had statistically significant positive correlations, in 2020, the correlation was weak whereas in 2019 there was a moderate positive correlation. This may suggest that there could have been effects caused by the lockdown during the COVID-19 pandemic on the performance of female pace bowlers. However, investigating the effects of the pandemic were beyond the scope of this study and therefore we chose not to delve deeper into the subject.

5.3.4.2 Dominant hip flexion

During back foot placement, male and female pace bowlers used the same technique. There was a weak negative correlation between dominant hip flexion and ball release speed for both parties. However, at front foot placement, males had a weak positive correlation ($\rho=0.258$, $p=0.002$) whereas there was a weak negative correlation ($\rho=-0.128$, $p=0.767$) for female pace bowlers.

There was a positive correlation between hip flexion one step after ball release and ball release speed for both male and female pace bowlers. This means that, the more the hip is flexed at front foot placement, the higher the ball release speed. To this author's knowledge, there is no published research reporting on the role of the dominant hip in ball release speed.

5.3.5 Knee flexion

5.3.5.1 Non-dominant knee flexion (front knee)

A weak negative correlation was found between knee flexion at back foot placement and ball release speed for both males and females which shows that they used the same technique to generate ball release speeds. This was the same for front foot placement, where there was a weak positive correlation between non-dominant knee flexion and ball release speed for both male and female pace bowlers. There was also a very weak positive correlation between non-dominant knee flexion one step after front foot placement and ball release speed for both male and female pace bowlers.

Our results show that a straighter knee at front foot contact results in higher ball release speeds. These results are comparable with other studies (Portus *et al.*, 2000, 2007; Loram *et al.*, 2005; Salter, Sinclair and Portus, 2007; De Asha *et al.*, 2009) which show that a straighter knee during front foot placement results in high ball release speeds. The study by Alderson (2007) showed a negative correlation between maximum front knee flexion (with a smaller value depicting a straighter knee) and ball release speed which means that the more a bowler flexed their front knee, the less their ball release speed therefore supporting the notion by other authors which states that a straighter knee helps produce high ball release speeds. Although Wormgoor, Harden and Mckinon (2010) did not find any correlation between front knee angle at front foot contact, there was a significant negative correlation between front knee flexion from front foot strike to ball release and ball release speed which corresponds to the results of our study and supports the notion expressed in various studies that the more a bowler extends their knee, the higher the ball release speed.

A straighter knee at front foot placement was seen as a strategy used by both male and female pace bowlers in this study. Lyons et al. (2023) confirmed that females used this same strategy as their male counterparts by confirming a positive correlation between front knee extension at front foot placement with ball release speed in their study population.

5.3.5.2 Dominant knee flexion (back knee)

Our results show that there is a weak positive correlation between dominant knee flexion at back foot placement and ball release speed for both male and female pace bowlers. This is also true for front foot placement and one step after front foot placement for both male and female pace bowlers. What is interesting here is that at back foot placement, where the dominant leg is the one that is taking the body weight, females seemed to use this as a strategy to increase ball release speed, while this was not used as a strategy in males. The more the knee flexion the higher the ball release speed in females. At front foot placement, the dominant leg is in the swing phase and for that reason may play less of a role in ball release speed as is seen in our study. There are a few studies in the past done to investigate the role of the dominant knee in generating ball release speeds as most studies focus on the non-dominant knee (Felton, Yeadon and King, 2020).

5.4 Conclusion

This chapter was a discussion of the findings of our research. This study revealed that females and males use different strategies to generate ball release speeds and this confirms previous findings by other authors. This study also shows that males have higher ball release speeds than females. Similar to previous studies, we found a positive correlation between age and ball release speed in females, height and ball release speeds in both males and females, and a positive correlation between knee extension at front foot placement as outlined in previous studies. The next chapter will be a conclusion of the study, highlighting the clinical implications of the study, limitations and strengths of the study as well as recommendations for future research.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusions

Our study aimed to explore two objectives. The first objective was to determine age, sex and anthropometric factors associated with high ball release speeds among elite pace bowlers. Our results show that there was a positive correlation between age and ball release speed in females but a negative correlation between age and ball release speed for male pace bowlers. As the male pace bowlers got older, the ball release speeds that they generated were lower.

The second objective was to determine the biomechanical factors associated with ball release speed among elite pace bowlers. Through this study, we have shown that trunk side flexion at front foot placement, trunk rotation at front foot placement as well as dominant hip flexion at back foot placement and knee flexion at back foot placement, at front foot placement and one step after ball release have positive correlations to ball release speed.

6.2 Strengths of this study

Our study population included the biomechanics reports of both males and females. This enabled us to outline any differences between the sexes in terms of strategies used to generate high ball release speeds.

The participants in the main study were tested in their natural environment. The bowling analysis were done in the cricket nets where their usual training takes place. This ensured that the findings were as close to the training setup as possible.

Inertial sensor units were used to record the bowling actions and these have high accuracy. The inertial sensors allowed for the capturing of the bowling action in an outdoor environment which contributed to the ecological value of the study.

6.3 Limitations of this study

The reports of participants included in this research report are of bowlers who were tested under different conditions because of the COVID-19 pandemic. Some participants were tested in 2019 under typical conditions while others were tested in 2020 after the national lockdown period due to the COVID-19 pandemic. This may have had an effect on their performance as they had not been training as usual due to the restrictions that were in place. Although a comparison between the two year groups was not within the scope of this research report, presenting these results separately may benefit other researchers embarking on a systematic review to allow for pooling of results.

Another limitation of this study is the low number of female players' reports available for inclusion in this study as compared to the male players' reports. This means the results may not be adequately compared between the two groups of pace bowlers because of the discrepancy in numbers. The low number of reports from female players available for inclusion is a function of the low number of players in the national and international arena.

6.4 Clinical Recommendations

This study can be used to guide further research. It has been suggested that extensor muscle groups of the knee are important in producing high ball release speeds (Feros, Young and O'Brien, 2019). Therefore, physiotherapists can work on targeted muscle strengthening programs which focus on the muscle groups responsible for the movements correlated to high ball release speeds. An eccentric muscle strengthening program of the quadriceps muscles has been suggested for pace bowlers (Feros, Young and O'Brien, 2019). Eccentric strength aids in absorbing ground reaction forces as well as keeping the knee straight (Johnstone *et al.*, 2014). Feros, Young and O'Brien. (2019) also suggested that hamstring strength may assist a bowler to achieve a straight front-leg technique at front foot placement and generate higher ball release speeds. The study by De Asha *et al. (*2009) also highlighted the importance of quadriceps muscle strength in generating high ball release speeds as they revealed that there was reduction in ball release speeds when the quadriceps muscles were fatigued thereby solidifying the need for strong quadriceps muscle to achieve high ball release speeds (De Asha *et al.*, 2009; Letter *et al.*, 2022b). Physiotherapists working with cricket teams can therefore use these findings to inform their decision making as far as choice of muscle strengthening program is concerned.

Because the body withstands a great amount of ground reaction forces acting on it during front foot placement, a considerable amount of strength is required for the back muscles. It is therefore imperative that physiotherapists working with cricket teams also focus on strengthening these muscles. Muscles that can be targeted are those responsible for trunk side flexion such as rectus abdominis, erector spinae, psoas, quadratus lamborum, external and internal obliques, latissimus dorsi, semispinalis thoracis, and deep posterior spinal muscles. They can also target muscles responsible for trunk rotation i.e rectus abdominis, tranverse abdominis, internal and external obliques. This could be beneficial for pace bowlers, not only in generating high ball release speeds but also in preventing stress related injuries.

These findings can also be used to inform coaching practices. Pace bowlers can be coached to maximise use of the components of the bowling techniques that increase ball release speed. Research shows that isometric body strength is important for generating ball release speeds and coaches should consider emphasising it in training (Kiely *et al.*, 2021; Letter *et al.*, 2022b).

The anthropometric qualities that had a significant correlation with ball release speed can be targeted by coaches through training for example, advice on weight management in order to maximise the players' full potential. The results can also guide coaches with talent identification and placing the players in appropriate positions that can enable them to maximise their potential. For example, coaches can predict the type of bowler that a cricket player will be and advise them accordingly. Research has shown that specific anthropometric characteristics can be used to predict a player's success in a particular sport (Koley, 2011) and it has shown that taller players have a potential of being fast bowlers as they possess a longer lever which generates greater ball release speeds (Middleton, 2011). Koley (2011) agreed with this notion as they noted that bowlers tend to have a taller stature as compared to batters and all-round players.

6.5 Recommendations for Future Studies

The limited number of studies which looked at female pace bowlers have been used to inform the coaching literature and practices using the findings made about male pace bowlers (Felton, Lister, Worthington, 2018; Lyons, 2023). This approach assumes that male and female pace bowlers use the same techniques to generate ball release speeds (Felton, Lister, Worthington, 2018). Our study shows that female pace bowlers use different strategies than those used by male pace bowlers in generating ball release speeds. This shows us that there is need for future research that focuses more on female pace bowlers. This can help to shape the coaching practices targeted toward female players rather than inferring from studies about male pace bowlers.

Research which looks at other groups of players such as junior cricketers can also be done. For example, studies that compare junior and senior cricketers can be carried out in order to investigate and identify any differences in their ball release speeds as well as different strategies used in achieving the different ball release speeds.

Our research shows that the mean ball release speeds for the players tested in 2020 were lower than those tested in 2019. There could have been due to the reduced training caused by the national lockdown period and therefore the influence of the COVID-19 pandemic on the performance of pace bowlers is a potential area of investigation by future researchers. A study can be done which compares data collected in 2019 with data collected in 2020 and highlight any differences that may have come up as a result of the restrictions brought on by the lockdown that came as a result of the COVID-19 pandemic.

6.6 Conclusion

This study has shown that male and female pace bowlers use different strategies to generate ball release speeds. It is therefore important that physiotherapists consider these differences when planning strength training programs for pace bowlers. Future studies that focus more on female pace bowlers can be done.

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Appendix I: Ethical clearance for primary study

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

20/11/2020

Professor B Olivier
School of Therapeutic Sciences
Departmentof Physiotherapy
Medical School
University

Sent by e-mail to: Benita.Olivier@wits.ac.za

Dear Professor Olivier

Re: **Protocol Ref No: M170726**
Protocol Title: *Injury prevention in cricket fast bowlers: the Fearless Fast Bowling Project*
Principal Investigator: Professor B Olivier

Thank you for your letter of 11/11/2020.

I confirm that your proposal to seek participant consent to the long-term storage of their data for possible future research has been noted and approved.

Thank you for keeping us informed.

Yours Sincerely

I. Burns
....
Mr I Burns
For the Human Research Ethics Committee (Medical)

CB Penny
....
Dr CB Penny, Chairperson, Human Research Ethics Committee (Medical)

Works2000/Iain0007/Acknowledge.docx

Appendix II: Ethical Clearance for secondary study

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

R14/49 Ms. Rumbidzai Murambasvina

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M210990

NAME: **(Principal Investigator)**	Ms. Rumbidzai Murambasvina
DEPARTMENT:	Physiotherapy School of Therapeutic Sciences
PROJECT TITLE:	Factors assocciated with high ball release speeds among cricket pace bowlers in South Africa
DATE CONSIDERED:	Ad hoc
DECISION:	Approved unconditionally
CONDITIONS:	Sub-study under M170726
SUPERVISOR:	Prof Benita Olivier and Dr Loveth Obiora
APPROVED BY:	CB Penny Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	20/10/2021

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

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. 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**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in **October** and will therefore be due in the month of **October** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature ____________________ Date ____________________

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix III: Turnitin report

Rumbie

ORIGINALITY REPORT

23%	20%	15%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	wiredspace.wits.ac.za Internet Source	3%
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5	Julia Somavilla Lignon, Melissa Querido Cárdenas, Natália Soares Martins, Tamires Silva dos Santos et al. "First record of Contracaecum australe (Nematoda: Anisakidae) infecting Neotropic cormorant (Phalacrocorax brasilianus) (Aves: Phalacrocoracidae) in southern Brazil with a phylogenetic analysis", Veterinary Parasitology: Regional Studies and Reports, 2024 Publication	1%
6	www.mdpi.com Internet Source	