THE ASSOCIATION BETWEEN BOWLING PERFORMANCE AND TRUNK MUSCLE STABILITY, STRENGTH-ENDURANCE AND THICKNESS IN ADOLESCENT PACE BOWLERS – A CROSS-SECTIONAL STUDY

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DECLARATION

I, Franso-Mari Olivier, declare that the work contained in this research report is my own work, except to the extent indicated in the acknowledgement sections.

This research report is being submitted for the degree of Master in Physiotherapy, at the University of the Witwatersrand, Johannesburg, South Africa.

This work has not been submitted for any other degree or examination in this or any other university.

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ABSTRACT

Background

The trunk is the centre of the kinetic chain, connecting upper and lower limbs and transferring energy during movement. Proximal stability serves as a base for quality movements distally. Trunk muscle stability and strength-endurance are associated with sporting performance. Asymmetrical sport-specific adaptation in the morphometry of the trunk muscles has been investigated and described in cricket pace bowlers, but not linked to or described in terms of the association with bowling performance.

Aim

The aim of this study is to investigate the association between bowling performance and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers.

Method

In this observational cross-sectional study, bowling performance, namely ball release speed and accuracy, was measured by means of a radar gun and accuracy target in the outdoor nets of the respective schools, where the 46 pace bowlers, aged 13-18 years old, were invited from. Trunk muscle stability was measured as the level passed on the Sahrmann Stability Scale and strength-endurance as the failing time in seconds according to the Bourbon Trunk Muscle Strength Test. Ultrasound imaging measured the thickness of external oblique, internal oblique, transversus abdominis and lumbar multifidus in millimetre. Spearman's correlations were used to determine associations between individual variables and a multiple linear regression analysis calculated predictors of bowling performance, including independent variables such as age, height and weight. Statistical significance was set at $p<0.05$.

Results

No association was found between trunk muscle stability and ball release speed ($r=0.278$; $p=0.061$) or accuracy ($r=0.026$; $p=0.866$). Stability, however, accounted for a 60.7% variance in ball release speed ($p=0.004$), increasing ball release speed by 3.570 units per unit increase in stability. Strength-endurance of the trunk muscle chains did not correlate to ball release speed ($r=-0.039-0.214$; $p=0.154-0.796$) or accuracy ($r=-0.062-0.131$; $p=0.385-0.801$). A moderate and fair relationship was found between ball release speed and transversus abdominis ($r=0.543$; $p=0.0001$) at rest and contracted ($r=0.440$; $p=0.002$), respectively. Non-dominant transversus abdominis showed a fair relationship with height at rest ($r=0.458$, $p=0.001$) and a moderate correlation with weight ($r=0.625$, $p<0.001$). On the dominant side, transversus abdominis at rest, showed a moderate relationship to ball release speed ($r=0.564$; $p<0.001$), height ($r=0.539$; $p<0.001$) and weight ($r=0.611$; $p<0.001$). Thickness of bilateral transversus abdominis at rest had an R-square value of .67 and ball release speed increased with 5.133 units for each unit increase in the thickness of the non-dominant transversus abdominis and 4.677 for that on the dominant side. Accuracy did not correlate with any independent variable, but weight (R-square value .207) was found to increase accuracy by .766 units for each unit increase. Bowling performance was found to be predicted by age (R-square value 0.084).

Conclusion

A direct association between bowling performance and trunk muscle stability and strength-endurance was not found. Trunk muscle stability – as a suppressor variable – was found to be a predictor of ball release speed. Trunk muscle thickness accounted for the variance in ball release speed and weight for that of accuracy. These findings implicate that adolescent pace bowlers may be able to improve ball release speed by increasing trunk muscle stability and bilateral transversus abdominis thickness. However, future research is needed to confirm this statement.

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ADIM	Abdominal “draw-in” maneuver
B-mode	Brightness mode
BR	Ball release
% change	Percentage change
cm	centimetre
CSA	Cross-sectional area
D	Dominant
EMG	Electromyograph
EO	External oblique
ICC	Intra-rater coefficient
IO	Internal oblique
kg	kilogram
km/h	kilometre per hour
LBP	Low back pain
LM	Lumbar multifidus
mm	millimetre
MRI	Magnetic Resonance Imaging
MVC	Maximum voluntary contraction
ND	Non-dominant
RFD	Rate of force development
1RM	1 repetition maximum
3RM	3 repetition maximum

s	second
SD	Standard deviation
SE	Strength endurance
Strength D	Strength of the dorsal chain
Strength L	Strength of the left chain
Strength R	Strength of the right chain
Strength V	Strength of the ventral chain
TMS	Bourbon Trunk Muscle Strength Test
TrAbd	Transversus abdominis
USI	Ultrasound Imaging

CHAPTER 1

Introduction and scope of the research report

1.1 Introduction

The performance of a pace bowler is measured in terms of the speed with which a ball can be delivered and how accurately the delivery is placed (Portus et al., 2000, Olivier et al., 2015) in relation to the wickets (Crewe et al., 2013, Woolmer et al., 2008) behind the batsman on strike. The pace bowling action is a repetitive, asymmetrical action, during which the trunk goes into hyperextension, lateral flexion to the non-bowling arm, then forward flexion and lastly rotation to the non-dominant side (Bartlett et al., 1996). From this action, it is clear that the pace bowler needs to be a well-conditioned athlete and the trunk stable and strong enough to absorb the repetitive forces that are elicited optimally, to perform the movements expected during the bowling action, without injury.

The "core" was described by Richardson et al. (1999) as a muscular box with the diaphragm superiorly, the abdominal muscles anteriorly, pelvic floor and hip muscles inferiorly and paraspinal muscles posteriorly. According to the literature, all movements of the body either originate or are coupled through the trunk (Akuthota and Nadler, 2004, Hedrick, 2000). The effect of trunk stability plays a vital part in athletes performing overhead throwing actions, because trunk stability acts as a torque-counter torque of diagonally related muscles during throwing (Akuthota and Nadler, 2004). Muscles of the trunk contribute to core stability according to their attachments on the vertebrae ("local" intersegmental control) or on the hips and pelvis ("global" spinal orientation) (Bergmark, 1989).

An athlete with a strong, stable core will transfer force more efficiently through the body in a straight line. In cases of poorly developed trunk stability, poor posture is usually the result and the athlete performs less efficient, jerky, movements (Brittenham and Brittenham, 1997). It is suggested that a high-level athlete will find it difficult to properly apply extremity strength without adequate core strength and stability (Hedrick, 2000). "Proximal stability due to the integrated core muscle activity, results in distal mobility and since the core is central in almost all kinetic chains in sporting activities, control of core strength, will maximise all chains of upper and lower extremities" (Kibler et al., 2006).

Strength-endurance is generally advocated as a prerequisite for athletic performance (Roth et al., 2014) and due to the repetitive nature of cricket pace bowling, this is a variable worth measuring.

Predictors of ball release speed have been investigated and the factors that have been identified are listed as found by these studies. A more extended knee at front foot impact (Crewe et al., 2013, Loram et al., 2005, Portus et al., 2004, Elliott et al., 1986), increased height and weight (Pyne et al., 2006, Lees et al., 2016) and a leaner, (Portus et al., 2000, Van den Tillaar and Ettema, 2004) stronger (Foster and John, 1987) upper body were some of the factors positively influencing ball release speed in younger players. In senior players, Glazier et al. (2000) found greater shoulder-wrist and arm length also correlated positively with increased ball release speed.

Predictors of accuracy have been investigated more in terms of what the physiological effects of certain conditions, such as repeated spells (Portus et al., 2000, Devlin et al., 2001) and hypo-hydration (Gamage et al., 2016, Devlin et al., 2001) would have on it. Cooling after a strenuous bowling session improved bowling speed as well as accuracy (Minett et al., 2012). Taliep et al. (2003) did not find accuracy to change during a 12-over spell, and put it down to the correlation found between eye-hand coordination and bowling accuracy.

Trunk movement is orchestrated by trunk muscle co-contraction. Muscles of the lateral abdominal wall as well as around the lumbar spine are activated in a specific movement pattern during the bowling action. Electromyography (EMG) studies have found that the activation value for lumbar multifidus is highest at back foot impact (Forrest et al., 2016). During the delivery stride and follow through, the external and internal oblique muscles contract, allowing trunk movement according to the anatomical attachments and insertions of these muscles and contribute to spinal stability through their action (Lehmann, 2006). Spinal stability is further contributed to by transversus abdominis, which has been shown to stabilise the spine before extremity movements take place (Hodges and Richardson, 1997a, Hodges and Richardson, 1997b).

Asymmetry of abdominal muscle thickness in adolescent fast bowlers has been reported in studies investigating the morphometry of the musculature. Olivier et al. (2013), Martin et al. (2017) and Gray et al. (2015) all reported an increased thickness of the internal oblique on the non-dominant side in pain free adolescent pace bowlers. Morphometry of lumbar multifidus has been reported on by Hides et al. (2008) and it was found that in elite cricketers without low back pain, lumbar multifidus measured larger on the dominant side. Olivier et al. (2016) negated this finding in their study on injury-free fast bowlers, and further noted a smaller multifidus on the non-dominant side as a precursor of injuring the low back. In healthy young adults lumbar multifidus was found to be symmetrical (Hides et al., 1992), and Teyhen et al. (2012) supported this in patients without LBP. Trunk musculature morphometry has been related to risk of injury in pace bowlers (Martin et al., 2017) as well as reporting side-to-side asymmetry at the beginning and end of a season (Olivier et al., 2013), but it has not yet been correlated to bowling performance.

In the sport and fitness industry, a statement such as "the well-trained core is essential for optimal performance…"(McGill, 2010) is regularly proclaimed in the popular media. This relationship of core stability and strength-endurance has been investigated in many other sporting codes, but not in cricket pace bowling. Increased core stability has been positively correlated to throwing velocity in handball (Manchado et al., 2017, Saeterbakken et al., 2011), an improved score on the Bunkie-test for rugby players (Van Pletzen and Venter, 2012), increased kicking velocity in soccer (Pedersen et al., 2006) and club head velocity in golf (Seiler et al., 2006), but it had no effect on swimming times (Scibek et al., 1999) rowing performance (Tse et al., 2005), or running economy (Stanton et al., 2004).

The lack of studies correlating cricket pace bowling performance to trunk muscle stability, strength-endurance and morphometry, encouraged the researcher to investigate whether an association existed. A high correlation was found between the strength-endurance of the ventral trunk muscle chain and the shot velocity rate in ice hockey players (Rogan et al., 2013). Evidence exists to partially support a co-existence of ball release speed and trunk muscle stability (Hilligan, 2008) in pace bowling. Manchado et al. (2017) and Haugen et al. (2016) supported this relationship in other sporting codes, although neither Stanton et al. (2004), Tse et al. (2005), nor Borghuis et al. (2008) found improved athletic performance due to increased core stability.

1.2 Problem statement

The association between ball release speed, accuracy, trunk muscle stability, strength-endurance and thickness in the adolescent pace bowler, has not yet been established. In a South African study an association was found between core stability and ball release speed in adult indoor pace bowlers, but, neither trunk muscle strength-endurance, thickness nor the accuracy of deliveries were measured (Hilligan, 2008). Ultrasonography has been used to measure the thickness of stabilising trunk muscles and asymmetries reported between dominant and non-dominant sides in pace bowlers (Gray et al., 2015, Olivier et al., 2013, Olivier et al., 2016, Hides et al., 2008), but no association was investigated between bowling performance and the thickness of the involved muscles. It has been accepted that proximal trunk muscle stability maximises upper and lower limb kinetic chains (Hodges and Richardson, 1997a, Hodges and Richardson, 1997b). This could prove to be applicable in the pace bowler as well and support the suggestion that the core musculature serves as the centre of the functional kinematic chain (Burkhart et al., 2003). The association between bowling performance and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers has not yet been determined in studies.

1.3 Research question

Is there an association between bowling performance (ball release speed and accuracy) and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers?

1.4 Aim of the study

The aim of this study was to determine the association between bowling performance (ball release speed and accuracy) and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers.

1.5 Objectives of the study

The objectives of this study were to:

1.) determine bowling performance including ball release speed using a hand-held radar speed gun and bowling accuracy using a zoned scoring target (Portus et al., 2000)

2.) determine trunk muscle stability using the Sahrmann Stability Scale (Stanton et al., 2004)

3.) determine trunk muscle strength-endurance of the dorsal, ventral and lateral chains using the Bourbon Trunk Muscle Strength Test (Granacher et al., 2014)

4.) determine thickness of the trunk muscles: transversus abdominis, external oblique, internal oblique and lumbar multifidus using ultrasound imaging (USI) (Whittaker, 2007)

5.) determine association between ball release speed and bowling accuracy

6.) determine association between bowling performance and trunk muscle stability, strength-endurance and thickness

1.6 Significance of the study

If an association between bowling performance and trunk muscle stability, strength-endurance and thickness is found, it can form the basis of future research where cause and effect can be established. Therefore, if for instance, bowling performance (speed and accuracy) is associated with a specific pattern of muscle morphometry as measured by USI, a randomized control trial might, for instance, investigate the effect of training for developing that morphometrical pattern, to improve bowling performance.

Studies reporting on trunk muscle morphometry in bowlers with low back pain or the effect of a stabilisation programme on low back pain in the general population are published frequently but cannot be made applicable to the purposes of prevention of injury in the pain free sporting population. The researcher, therefore, felt it necessary to investigate this particular population of pain free adolescent pace bowlers, because this age group is a population at risk, and should be able to benefit from age specific research.

Although only associations can be established in this study due to its cross-sectional nature, and taking into account that no longitudinal studies are available yet, it will be worth including trunk muscle rehabilitation exercises into coaching and training regimes. Pace bowlers could be screened, before any coaching or training commences so that both coaches and pace bowlers have a baseline to work from, allowing for more evidence-based coaching and training.

1.7 Organisation of research report

Chapter 1

- The introduction to the research report on establishing the association between bowling performance and trunk muscle stability, strength-endurance and thickness. The problem of trunk musculature associated with performance is presented and the aim, objectives and significance of the study are laid out.

Chapter 2

- This chapter reviews the literature on the following aspects: the bowling action, bowling performance, trunk muscle stability and strength-endurance and trunk muscle thickness and asymmetry.

Chapter 3

- The methodology of the study is described in this chapter, including the population, sample size, inclusion and exclusion criteria. The outcome measures and method of measuring is explained in detail. Ethical consideration is discussed as well as the statistical analysis of data.

Chapter 4

- Chapter 4 presents the results of the study after statistically analysing them.

Chapter 5

- The findings of the study are interpreted and related to existing literature.

Chapter 6

- The conclusion of the study is discussed in this chapter as well as the strengths and limitations of the study. Recommendations are made for future research according to what was found in the study.

CHAPTER 2

Literature review

2.1 Introduction

Cricket is a strategic sport watched, played and enjoyed worldwide among players of all ages and genders, consisting of bowling, batting, wicket keeping and fielding. Players on a team, therefore, have many roles to fulfill. Bowling is divided into pace bowling and spinning. The pace bowler is the proverbial oncoming steam train, aiming to outwit the batsman on strike with a good quality delivery at maximum ball release speed and accuracy, consisting of a good line and length (Woolmer et al., 2008, Crewe et al., 2013). The value of a pace bowler is measured by his bowling performance, which includes ball release speed and the accuracy of the delivery (Portus et al., 2000, Olivier et al., 2015). Pace bowlers may contribute greatly to a team's success, when bowling accurately at the right speed and taking wickets or putting the opposition's run rate under pressure. However, pace bowlers may also pose great risk to a team's success when they fail to do so and allow the opposing team's batsmen to score runs against them. It would therefore be advantageous for a pace bowler, the coach and trainer to know whether trunk muscles are correlated to bowling performance, so that they can address training the correct muscles correctly, to improve their own performance.

Trunk musculature is a topic frequently raised when sport and performance are discussed. Co-contraction of trunk muscles and the connection of upper and lower limbs via the abdominal fascia is responsible for core stability, particularly important in athletes performing overhead activities (Van Dieen et al., 2003). The terms core or trunk stability and strength-endurance are used often and may cause a great deal of confusion when used without a dedicated definition (Haugen et al., 2016). These terms are also used in association with enhanced performance or as the predictor thereof (Tse et al., 2005, Granacher et al., 2014, Stanton et al., 2004, Hibbs et al., 2008). Observing the bowling action in adolescent male pace bowlers has lead the researcher to investigate the association between bowling performance and trunk muscle stability, strength-endurance and morphometry in terms of thickness, as measured by ultrasound imaging. Many studies have focused on elite athletes (Pedersen et al., 2006), collegial athletes of different sporting codes (Tse et al., 2005, Manchado et al., 2017, Stanton et al., 2004, Scibek et al., 1999, Van Pletzen and Venter, 2012) or adult amateur and adolescent pace bowlers locally (Olivier et al., 2015, Loram et al., 2005, Gray et al., 2015). This literature review explores the topics related to bowling performance of pace bowlers (adult as well as adolescents) and trunk muscle stability, strength-endurance and morphometry and contains literature published between 1977 and 2017. The studies referred to in this literature review were sourced through a search on the following data bases: MEDLINE via Pubmed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Cochrane Controlled Trials Register in the Cochrane Library, Physiotherapy Evidence Database (PEDro), ProQuest 5000 International, ProQuest Health and Medical Complete, EBSCO MegaFile Premier, Science Direct, SCOPUS and SportDiscus. The following keywords were used: cricket, fast bowling, pace bowling, ball release speed, accuracy, bowling performance, lumbo-pelvic stability, core stability, core strength, core strength-endurance, trunk stability, trunk muscle strength-endurance, trunk muscle morphometry, abdominal wall muscles, rehabilitative ultrasound, ultrasound imaging, lumbar multifidus, external oblique, internal oblique, transversus abdominis, puberty, adolescent.

2.2 The bowling action

In order to understand the trunk musculature and relationship to bowling performance, it is important to understand the bowling action of the pace bowler. The pace bowling action is an asymmetrical action, described by Bartlett et al. (1996) and is divided into different stages, namely: run-up, pre-delivery stride, delivery stride and follow-through, depicted in figure 2.1. Performing this action, the bowler starts by walking or rhythmically jogging from his marker (15 to 30 metres away), gradually increasing his approaching speed to the crease. Leaping into the air with the left foot (in case of a right-handed bowler) marks the beginning of the pre-delivery stride, just before the back foot (right) strikes the ground. During this stride, the shoulders are pointed sideways down the wicket and the right foot passes the left to land parallel to the wicket. The delivery stride commences when the back foot strikes the ground. Weight is moved onto this foot and the trunk leans backwards and sideways to the non-delivering arm. Depending on the technique a bowler has acquired, the trunk moves into hyperextension and or lateral flexion to the non-dominant side. This phase can be further divided into front foot strike and ball release. The peak vertical impact force on front foot strike equals between 3.8 (Foster and Elliott, 1985) and 6.4 (Elliott B, 1992) times body weight. The anterior-posterior braking forces are around twice the body weight according to Elliott and Foster (1984), Elliott et al. (1986), Foster et al. (1989), Mason et al. (1989), Saunders and Coleman (1991). When the bowler lands on the front foot, the delivery arm circumducts to above his head, the trunk is flexed to the non-dominant side and after delivering the ball, the trunk flexes forward and rotates over the front foot. Elliott and Foster (1989) suggested the bowling arm end in a position where it follows down the outside of the front leg, figuratively brushing the ground, decelerating the bowler.

The trunk serves as the proximal base for extremity movement throughout this bowling action and movement is coupled through the trunk (Akuthota and Nadler, 2004). The repetitive execution of the bowling action activates the trunk muscles in the same asymmetrical manner with each delivery, i.e. trunk hyperextension, lateral flexion to the non-dominant side, forward flexion and lastly lateral flexion-rotation to the non-dominant side (Bartlett et al., 1996).

i) Run-up *ii) Pre-delivery stride* *iii) Back foot strike*

iv) Delivery stride *v) Front foot strike* *vi) Follow-through*

Figure 2.1 The bowling action: i) run-up, ii) pre-delivery stride, iii) back foot strike, iv) delivery stride, v) front foot strike) and vi) follow-through (post ball release)

2.3 Bowling performance

Bowling performance has been thoroughly investigated in the literature. The speed of a delivery and the accuracy thereof determines the performance of the pace bowler (Portus et al., 2000, Olivier et al., 2015). Similarities and differences will be highlighted between the different studies from the literature. Studies will be discussed according to the factors influencing or predicting bowling performance.

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2.3.1 Ball release speed and accuracy

The factors influencing ball release speed and accuracy, are: anthropometric values (Pyne et al., 2006, Foster and John, 1987, Glazier et al., 2000, Portus et al., 2000), biomechanics or technique (Portus et al., 2004, Crewe et al., 2013, Loram et al., 2005, Lillee, 1977) including run-up velocity (Salter et al., 2007, Glazier et al., 2000, Duffield et al., 2009), lower body strength (Pyne et al., 2006), trunk muscle stability (Hilligan, 2008), physiological effects and repeated spells (Devlin et al., 2001, Gamage et al., 2016), intervention programmes (Petersen et al., 2004, Freeston and Rooney, 2008), skill-level (Phillips et al., 2011) and external factors such as pitch length (Elliott et al., 2005).

2.3.1.1 Anthropometric values

Anthropometric values play a role in ball release speed, as reported by Pyne et al. (2006). According to this study, the best predictors of ball release speed are height, body mass and upper body strength. Foster and John (1987) supported the latter correlation found, but this finding was negated by another study on adolescent pace bowlers with a small sample size of 12 participants (Loram et al., 2005). A moderate to good correlation was found ($r=0.626$; $p<0.05$) between ball release speed and the total arm length in senior players, measured from shoulder to wrist. This finding could be explained by the increased radial length, thus, increasing speed on axial rotation during the delivery (Glazier et al., 2000). Ball release speed correlated moderate to good with chest composition ($r=0.678$; $p=0.008$) on cricketers with a mean age of 23 years, in a study conducted by Portus et al. (2000). According to findings of this study, participants with a larger (greater chest girth measurement) and leaner (smaller skinfold measurement) torso bowled faster than participants with smaller and less lean upper torsos. Anthropometric data collected via dual energy X-ray absorptiometry (DXA) on 12 first class English fast bowlers and 12 non-athletic controls, also confirmed that fast bowlers were significantly taller, heavier and possessing greater lean trunk mass (Lees et al., 2016).

2.3.1.2 Biomechanics (or technique)

Many different aspects of the pace bowling technique have been investigated and found to be related to ball release speed, as summarised in table 2.1. Higher peak ground reaction forces at front foot impact are associated with increased ball release speeds (Portus et al., 2004, Crewe et al., 2013). This could be explained by a higher body mass, run-up speed and increased braking action of the knee during this phase (Portus et al., 2004). In addition, increased shoulder counter-rotation ($r=0.541$; $p,<0.01$) of forty male adolescent fast bowlers of the district or state cricket squads, correlated moderate to good with increased ball release speed as found by Crewe et al. (2013). Bowlers who deliver the ball with a more extended knee at front foot impact tend to attain higher ball release speeds (Loram et al., 2005, Crewe et al., 2013). It is clear that the pace bowling technique can be adapted to accomplish high ball release speed.

Table 2.1 Correlations between different variables and ball release speed according to literature

Author	Variable	Ball release speed correlation
Portus et al. (2004)	Peak ground reaction force	r=0.65 p<0.05*
Loram et al. (2005)	More extended knee at front foot impact (FFI)	r=0.72 p<0.01*
Crewe et al. (2013)	Shoulder counter-rotation	r=0.54 p<0.01*

*indicates statistical significance (p<0.05)

A moderately significant correlation between higher peak ground reaction forces at front foot impact and faster ball release speed was found by Portus et al. (2004). This could be explained by a higher body mass, run-up speed and increased braking action of the knee during this phase. Crewe et al. (2013) supported the finding and also found a more extended knee on front foot impact and increased shoulder counter-rotation to correlate positively with increased ball release speed. Loram et al. (2005) investigated determinants of ball release speed in adolescent pace bowlers and was also able to draw a correlation between ball release speed and an extended front knee on front foot impact.

In a single case study, run-up velocity was found to be a determinant for ball release speed by Salter et al. (2007). This finding was supported by Glazier et al. (2000). Duffield et al. (2009), furthermore, found the final five metres of the run-up together with the distance of the run-up to correlate similarly (r=0.7-0.72) to ball release speed in two six-over repeated spells. A great centre of mass deceleration during the delivery stride, created by the run-up length, speed and rhythm should be developed to allow the effective transfer of energy to the trunk and arm, hereby maximizing ball release speed generation, according to Ferdinands et al. (2010). No studies, however, could be found correlating accuracy of a delivery with the velocity of the run-up.

Not only ball release speed, but also accuracy forms part of the bowling performance realm. Accuracy of a delivery was negatively affected during the second half of an eight over spell of fourteen first class bowlers, due to an increase in shoulder counter-rotation (Portus et al., 2000). Technique, therefore, seems to be a contributing factor. Lillee (1977) suggested that a bowler keeps his eyes fixed on the wicket during the delivery phase and throughout the follow-through for improved accuracy. Levels of hydration played a role in bowling accuracy, where bowlers delivered 36 balls in a thermoneutral environment, then had an exercise session in a warmer environment and bowled another 36 deliveries. Fluid intake was restricted in the one trial and the accuracy of those bowlers was negatively affected in terms of line and length of the delivery (Devlin et al., 2001). This finding was negated by Taliep et al. (2003) when no change could be detected in bowling accuracy over a 12 over spell. They found a correlation between eye-hand coordination and accuracy and explained their findings against this background. Although the above studies are touching upon the issue of bowling technique and its role in delivering an accurate ball, studies investigating bowling accuracy are lacking.

2.3.1.3 Lower body strength

Loram et al. (2005) found no correlation between ball release speed and peak torque flexion and extension of the knee in adolescent pace bowlers. Pyne et al. (2006), however, found lower body strength to be a partial predictor of ball release speed. The test used for lower body strength in their study – single leg vertical jump - was chosen to closely mimic athletic movement and because junior bowlers did not have sufficient strength or experience to perform the 1 repetition max (1RM) or the 3 repetition max (3RM). No literature could be found where a strong relationship was drawn between bowling accuracy and lower body strength.

2.3.1.4 Trunk muscle stability

A South African study conducted by Hilligan (2008) on male indoor pace bowlers found a correlation between ball release speed and core (trunk) stability. This study, however, drew a relationship between ball release speed and trunk stability only, without taking thickness of the trunk muscles into account or accuracy of a delivery. Portus et al. (2000) also investigated trunk stability in a population of first-grade cricketers (n=14) with a mean age of 23 years old, using an inflatable pressure biofeedback, because of the idea that a strong mid-torso plays a vital part in efficiently producing force (Faccioni, 1994, Saunders, 1995). Participants with greater scores on trunk stability, as measured by the distance from the extended leg to the ground when the pressure biofeedback was positioned in the lumbar lordosis, had a more flexed knee on front foot impact. They found this challenging to explain, but they could only suggest that the bowlers bowling with bent knees, adapted the activation of their trunk musculature to the extent of using the trunk as a rigid lever, instead of the lower limb to produce ball release speed. Slower ball release speeds have been correlated to landing on a more flexed knee during front foot impact (Crewe et al., 2013, Loram et al., 2005). No more literature was available correlating trunk muscle stability to bowling performance of the pace bowler.

2.3.1.5 Physiological effects and repeated spells

Exercise-induced hypohydration proved to have a small detrimental effect on bowling accuracy in a small sample size (n=7) over 36 deliveries under different thermal and hydration conditions. This negative effect on bowling accuracy could be put down to impaired skilled motor performance, although it is interesting to note that these conditions had no effect on ball release speed (Devlin et al., 2001).

In a study investigating 14 first-grade cricketers, the ball release speed did not change and accuracy showed non-significant variations during an eight over spell (Portus et al., 2000). Similar findings were made by Devlin et al. (2001), although in the latter study the accuracy was negatively affected. The physiological effect of hypohydration (Devlin et al., 2001) or dehydration (Gamage et al., 2016) both negatively affected accuracy of a delivery. In dehydrated pace bowlers, ball release speed as well as the line of the ball was affected, but not the length.

2.3.1.6 Intervention programmes

The effect of various intervention programmes on bowling performance has been studied to scientifically develop performance enhancement programmes. In a study by Petersen et al. (2004*)*, bowlers took part in a 10-week modified weight training programme, bowling with overweight (161-181g), regulated (156g) and underweight (131-151g) balls three times a week. Ball release speed increased negligibly, but bowling accuracy was affected for the worse. Freeston and Rooney (2008) added two additional progressive throwing (not bowling) training sessions per week to the program of 18 sub-elite cricketers. Cricketers adhered to this programme for eight weeks. Overhead throwing velocity increased without an effect on throwing accuracy. Bowling speed was not an outcome measure of this study.

2.3.1.7 Skill-level

Adolescent pace bowlers between the ages of 13 and 18 years old, would typically have started playing cricket from the age of nine. Therefore, these adolescents will have between a minimum of five and a maximum of nine years playing experience at different levels, i.e. school A-team, district team, regional team or provincial team. The variation in age and skill-level within the sample is therefore, acknowledged by the researcher.

Phillips et al. (2011) compared pace bowlers of different skill-levels (national, emerging and u/19 juniors) performing deliveries of short, good and full lengths. A good delivery is typically referred to as having a good line and length. Woolmer et al. (2008) described the line as the horizontal location relative to the wicket and the length as the point where the delivery lands on the pitch. Deliveries are also divided into short, good and full length. Short deliveries are aimed at bouncing to the batsman’s head and used as an intimidation tactic. Good length deliveries are aimed at the top of the off-stump, or “the uncertain zone”, as the batsman is unsure whether to move forward or back when facing a delivery of this length. Full deliveries are aimed at the batsman’s feet and are particularly difficult to play. It was found that the more skilled participants could adapt their action to enhance bowling accuracy better than the juniors. Full length balls were more difficult to perform for all three skill-levels and short and good deliveries were easier for all participants. Junior bowlers were least accurate across the different length deliveries, but as consistent as the more skilled participants. From this study is it therefore, clear that bowling performance is related to skill-level.

2.3.1.8 Puberty and the effect on body composition and skill-level

During puberty, all the main components of body composition increase, namely: total body fat, lean body mass and bone mineral content. In boys, a rapid increase in fat free mass takes place between the ages of 12 and 15 years (Siervogel et al., 2003). Loomba-Albrect and Styne (2009) supported this and further reported that it thereafter stabilizes between 17 and 19 years old. Puberty is divided into stages, according to the Tanner scale (Tanner, 1962). The different stages are: pre-pubertal (stage 1), through puberty (stage 2-4) and post-puberty (stage 5). Common measures of puberty, are: sexual maturation indicators (based on pubic hair and genital development), bone growth measurement (epiphyseal growth of wrist and hand as examined on X-rays) and landmarks of physical growth (age at peak height velocity). The timing of these various maturational landmarks is strongly related to concurrent body composition (Siervogel et al., 2003).

Elite and non-elite 11-year old soccer players were examined (three to four times) over a two-year period, to determine the relationship between muscle strength, training levels and testosterone levels. Development of strength was significantly related to changes in serum testosterone concentrates. It is important to note, that both elite (those players playing at the top level available for their age group) and non-elite players had an increase in muscle strength. A strong positive relationship was, however, found, between being an elite player and the level of strength, independent of the testosterone level and growth factor. This indicates that development in strength could be related to factors associated with performing as an elite athlete/player. The development of strength is therefore, also related to some extent to muscle hypertrophy and recruitment of the neuromuscular system at a greater level when you are an elite athlete, due to the training exposure from an early age (Hansen et al., 1999).

The degree of maturation also affects the response to training. Up until the age of 15 years old, isometric quadriceps strength of athletic and non-athletic boys measured similarly. After this age, the athletic boys tested significantly stronger (Maffuli et al., 1994). Mero et al. (1991) believed hormonal changes seem to be responsible for the maturation of the metabolic response to training. This was supported by Asmussen and Heeboll-Nielsen (1955) and Carron and Bailey (1974) as they agreed that the acceleration of muscle strength during puberty possibly related to elevated androgen hormones.

The researcher, therefore, was aware of the fact that in this sample, the participants were at varying degrees of maturation, being adolescent boys between 13 and 18 years of age.

2.3.1.9 Injury risk related to age and level of experience

Young pace bowlers are at risk of developing injuries (Payne et al., 1987). In a study of 24 young (16-18 years old) elite pace bowlers, 54% was diagnosed with a pars interarticularis defect by MRI and 63% had intervertebral disc degeneration. Back pain was always associated with abnormal X-rays in this study. The repetitive nature of the bowling action seems to be the cause of these defects. Excessive extension during the delivery phase seems to be the cause of the high incidence of spondylolisthesis, whereas, excessive rotation on delivery is implied in unilateral defects of the pars interarticularis on the non-dominant side (Hardcastle et al., 1992).

Age may affect the injury pattern of a pace bowler. Of the 70 pace bowlers recruited from “Centres of Excellence” from three “First Class”Counties, 10% of these bowlers between the age of nine and 21 (mean age 14.9 years old) developed back pain. Low back pain is less common to develop in the skeletally immature, than thereafter (Gregory et al., 2002).

Elite pace bowlers (mean age 16.8 years) were tested prior to as well as after a season (n=82). Eleven percent of these bowlers sustained a stress fracture to a vertebra between L4 and S2 (Foster et al., 1989). The mean age of the bowlers in this study increased their vulnerability to fractures, as the disc is still relatively elastic, but most shear forces are transmitted through the facet joints. The neural arch also is not completely ossified yet, making it more vulnerable to the repetitive stress placed upon it (Cyron, 1977).

2.3.10 Pitch length

The effect different pitch lengths have on bowling performance of junior cricketers (under 11 to under 15) was investigated by Elliott et al. (2005). Participants had to bowl on three different pitch lengths, namely: 16 metres, 18 metres and 20.12 metres. Bowling accuracy improved across all age groups on the shorter pitches, although ball release speed remained unchanged. The under 15 subgroup (adolescents) of this study bowled significantly less accurately on the 20.12 metres pitch, but ball release speed was not negatively affected. This supports the existence of the relationship between bowling performance and length of the pitch.

2.4 The association between ball release speed and accuracy

Ball release speed and accuracy are the two components of bowling performance. Sachlikidis and Salter (2007) determined a trade-off to exist between these two components in high performing u/17 and u/19 cricketers (n=7) during dominant arm throwing. However, Duffield et al. (2009), could not correlate ball release speed and accuracy (r=0.05) during a six-over spell. The relationship between physiological and performance responses was investigated and no decrement in either ball release speed ($p=0.41$) or accuracy was found, between overs one and two.

In highly skilled athletes, this speed-accuracy trade-off seemed to disappear (Beilock et al., 2002). Expert and novice golfers were putting on indoor greens under instruction of either speed or accuracy. The expert golfers performed better under speed instructions compared to their novice counterparts needing more time to perform accurately. These findings were explained by suggesting that the highly skilled athletes no longer needed attention to and control of the performance process like in the initial stages of mastering new performance processes.

In a study of twelve overs, double that of Duffield et al. (2009), ball release speed decreased significantly from the first ($32.9\pm2.1 m.s^{-1}$) to the twelfth over ($32.1\pm1.8 m.s^{-1}$) (Taliep et al., 2003). Accuracy did not change significantly, and was explained by the author according to the good to excellent correlation of accuracy to hand-eye coordination ($r=0.82$, $p<0.01$).

In the age group u/11, u/13 and u/15, ball release speed remained constant during five deliveries each on different pitch lengths, namely; 21.12m, 18m and 16m. Accuracy, however, improved across all age groups for deliveries on the shorter pitch (Elliott et al., 2005). Ball release speed was also not correlated with accuracy in short ($r=-0.106$, $p=0.282$), good ($r=0.061$, $p=0.369$) or full deliveries ($r=-0.093$, $p=0.306$) across pace bowlers of different skill-levels (national squad, emerging squad or junior u/19 squad) (Phillips et al., 2011).

From the literature it is evident that opposing views exist regarding the association between ball release speed and the accuracy of the delivery.

2.5 Trunk muscle stability and strength-endurance

The bowling action should afford a clear explanation as to the muscles and trunk function in the pace bowler. The trunk movements during the bowling action include hyper extension, lateral flexion to the non-dominant side, forward flexion and flexion-rotation to the same side (Bartlett et al., 1996). Movement of the trunk takes place because of muscle contraction in specific phases of the delivery. Trunk muscle stability and strength-endurance and the functional role in bowling performance will be discussed in the following section.

2.5.1 Definitions and misconceptions

The term core or trunk stability and strength is commonly used, but often used undefined and within different contexts in the sport and fitness industry. In the media, ungrounded statements are proclaimed relating core stability and strength to enhanced performance (Drock, 2003). The emphasis placed on strengthening of the core encourage coaches and athletes to train accordingly, strengthening muscles of the trunk and pelvis as well as the muscles connecting the trunk to the extremities (Liemohn and Pariser, 2002). Hibbs et al. (2008) also noted published literature without scientific rationale, promoting training the core for performance enhancement in the sporting sector.

Many different definitions exist for core stability (Ebenbichler et al., 2001, Van Dieen et al., 2003, McGill, 2001, Tse et al., 2005, Bergmark, 1989, Akuthota and Nadler, 2004, Panjabi, 1992, Kibler et al., 2006, Fig, 2005). A Delphi study (Majewski-Schrage et al., 2014) formulated core stability as the ability to achieve and sustain trunk control at rest as well as during movements of precision. Consensus was not reached on assessment techniques, though, 93.3% of the experts agreed on muscles being one of the components of core stability. Panjabi (1992) described core stability as a combination of the active spinal muscles, the passive spinal column (ligaments and bones) and the neural control unit to maintain a safe intervertebral range of motion limit wherein an individual can perform activities of daily living. Richardson et al. (1999) described the muscular box with the diaphragm superiorly, the abdominal muscles anteriorly (Figure 2.2), pelvic floor and hip muscle inferiorly and paraspinal muscles posteriorly.

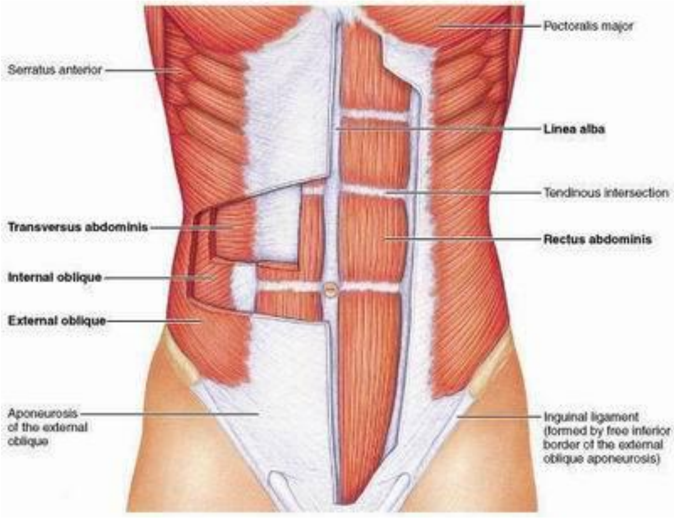

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Figure 2.2 Muscles of the anterior abdominal wall

Researchers focusing on athletic performance, included muscles affecting core stability from the sternum to the knee, with a focus on the abdominal region, lower back and hips (Fig, 2005). Akuthota and Nadler (2004) explained this term as the muscular control required around the lumbar spine to maintain functional stability with or without movement of the extremities. Kibler et al. (2006) expanded on this by describing core stability as: “the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segments in integrated athletic activities.” They included muscles of the trunk and pelvis as providing stability, but also mobility.

Strength-endurance of the trunk muscles can be described as the number of consecutive repetitions the individual can lift a specific weight or hold the weight for a length of time (Nelson et al., 2005). Endurance of the trunk muscles can therefore be measured by repetitively lifting the body weight to the point of failing or maintaining the position – such as the plank exercise - for a length of time. Not only strength of the core (trunk), but also endurance are often described as prerequisites for athletic performance (Roth et al., 2014).

2.5.2 The role of trunk musculature during extremity movement

According to Hedrick (2000), Brittenham and Brittenham (1997) believe all movements originate and are coupled through the trunk, therefore, well developed trunk strength will allow movements of the lower and upper extremities to be connected through the trunk and result in improved efficiency of performance. The trunk makes movement possible in numerous planes during most sports, for instance pace bowling in cricket. Referring to the bowling action described earlier, flexion and extension of the trunk takes place in the frontal plane, lateral flexion in the sagittal plane and rotation in the horizontal plane.

Ebenbichler et al. (2001) argued that muscles are the greatest contributor to maintaining spinal stability under various conditions. According to Van Dieen et al. (2003) this trunk stability is created by muscles co-contracting and connecting upper and lower limbs via the abdominal fascia. This is particularly important in athletes performing overhead activities. This stable connection acts as a torque-counter torque of diagonally related muscles during the throwing action (Ebenbichler et al., 2001). Both Hodges and Richardson (1997a) and Hodges and Richardson (1997b), showed that transversus abdominis activated even before an extremity started moving. This implied that the transversus abdominis muscle acts as a stabiliser of the trunk when power is produced by the extremities. Akuthota and Nadler (2004) supported this finding and further explained that when transversus abdominis contracts, the intra-abdominal pressure increases, tensioning the thoraco-lumbar fascia. This fascia connects to the upper and lower limb, hence forming a corset around the abdominals by incorporating the fascia posteriorly, the abdominal fascia anteriorly and the oblique muscles laterally. External oblique, internal oblique and transversus abdominis increases the functional stability of the spine by increasing the intra-abdominal pressure. Kibler et al. (2006) were also supportive of the increased intra-abdominal pressure, preceding movement of the upper limb due to muscle contraction. The trunk is central to all kinetic chains in sport, therefore, control of core strength will maximize kinetic chain function of both upper and lower extremities. This explains the trunk as the stable proximal base allowing the generation and transferring of energy to the distal, smaller body parts.

Both McGill (2001) and Cholewski and Van der Vliet (2002) are of the opinion that all trunk muscles contribute to stability, depending on the activity. These muscles are categorised into muscle attaching directly onto the vertebrae (uni-segmental, namely: multifidus and multi-segmental, namely: quadratus lumborum and longissimus) and those not attaching directly onto the vertebrae, namely: the abdominal wall and iliocostalis.

Forrest et al. (2016) investigated the muscle activation patterns of muscles in the lumbo-pelvic region in adolescent pace bowlers, using electromyography (EMG). They found that lumbar multifidus, for instance, activated at back foot strike right through to post-ball release. This is the phase during which the vertical and shear forces are high, suggesting that these posterior muscles act as stabilisers of the spine during bowling, when above mentioned forces are high.

2.5.3 Athletic performance and trunk muscle stability and strength-endurance

Studies investigating the association between performance and trunk muscle stability and strength-endurance will be discussed in this section. Tse et al. (2005) examined the effectiveness of a core endurance protocol for collegiate rowers (mean age 21±1) twice per week for eight weeks. No significant changes could be detected on performance testing or on the rowing ergometer in post-intervention testing. Stanton et al. (2004) investigated the effect of short-term Swiss ball core conditioning training on the running economy of male athletes (mean age 15.5±1.4). Core stability was assessed using the Sahrmann Stability Scale with the inflatable pressure biofeedback in the lumbar lordosis, like in this study. Electromyograph electrodes were applied to back and abdominal muscles and running economy was measured. After six weeks of Swiss ball training twice a week, the runners improved on their core stability scores, without any effect on their athletic performance, i.e. running economy. Scibek et al. (1999) supported these findings when swimmers also improved in terms of core stability, but without enhancing swimming performance in terms of better times. Borghuis et al. (2008) and Hibbs et al. (2008) concluded that no clear evidence of a relationship could be found in the literature between sporting performance and core stability, although improvement of core stability and strength occurred.

On the contrary, Granacher et al. (2014) investigated the effect of core strength training on the physical fitness of 27 adolescents (mean age 14±1). The components of physical fitness measured were: strength-endurance of all trunk muscle chains, standing long jump,20-m sprint, stand-and-reach test, jumping sideways and the Emery and Y-balance test. These participants’ physical fitness improved after the six weeks training programme on stable and unstable surfaces. Although their fitness levels as measured by the above mentioned outcomes improved, one has to bear in mind that this cannot be compared to athletic performance per se. School-going children (n=164) aged 11.5±2.5 years participated in a 6-week intervention programme where 10 different dynamic core conditioning exercises were executed for 5 minutes at the beginning of their physical education classes. Trunk muscle endurance as measured using 5 different tests, significantly increased in this population (Allen et al., 2014). Hilligan (2008) found an association between ball release speed – one of the components of pace bowling performance – and core stability in adult male indoor cricketers aged 18-35 years, using a pressure biofeedback placed under the abdomen and lumbar lordosis respectively. Core stability in this study was measured in terms of the ability of the participants to perform the abdominal "draw-in", how long they were able to contract it and whether lumbopelvic stability was present when the participant performed loaded movements by means of leg-levers. Nesser et al. (2008) reported a significant relationship between sprinting, throwing, jumping performance and core muscle strength.

In golf, Seiler et al. (2006) measured an increase in club head velocity with increased core stability. Reed et al. (2012) also supported a relationship of core stability to golf performance. The same relationship was found in the tennis serve by Fernandez-Fernandez et al. (2013) as well as to accuracy of throwing (Hirashima et al., 2002). Greater kicking velocity was measured in elite-soccer players (Pedersen et al., 2006) after core training and Van Pletzen and Venter (2012) reported an improved Bunkie test score for rugby players who had higher levels of core strength. Handball studies may apply partially to pace bowling, as performance is measured in terms of throwing velocity and accuracy. In two separate studies, the throwing velocity improved after players underwent core training (Manchado et al., 2017, Saeterbakken et al., 2011). A continuous increase in EMG activation in planking prone and sideways as well as in the dorsal position in high-level football players was noted in the performance strength-endurance tests of the dorsal, ventral and lateral trunk muscle chains (Roth et al., 2014). Amateur ice hockey players' core muscles were investigated by testing the maximum voluntary contraction (MVC), strength-endurance (SE) and rate of force development (RFD). Strength-endurance of the ventral trunk muscle chain correlated good to excellent ($r=0.787$; $p=0.02$) with the shot velocity rate (Rogan et al., 2013).

From this section is it clear that opposing literature is published on the association between athletic performance and trunk muscle stability and strength-endurance. The number of studies investigating the effect that trunk stability and strength-endurance have on spinal pathology and reducing low back pain (LBP), are far outweighing studies investigating this relationship with performance. These findings of the afore mentioned studies are not necessarily applicable to the sporting world. Hibbs et al. (2008) agreed that the effect of trunk stability and strength on performance of the elite-athlete has not yet been researched sufficiently. No studies on how bowling performance in the pace bowler relates to trunk muscle stability and strength could be found. Studies investigating other sporting codes were therefore, discussed, to establish some sort of relationship with performance. The researcher is, however, aware of the fact that this is athletic performance and not pace bowling performance specifically.

Inconsistent outcomes relating to the association between performance and trunk muscle stability and strength-endurance could be partially due to the many different definitions regarding stability and strength-endurance of the trunk. Another reason could be that no gold standard exists for measuring these variables and that not all tests used in studies are valid or reliable. Cricket pace bowling studies investigating the relationship between bowling performance and stability and strength-endurance of the trunk are lacking, therefore, the researcher is interested in adding to the body of knowledge of an under-investigated topic.

2.6 Trunk muscle thickness

The text contained in the following paragraphs aims to explain what the measurement of trunk muscle thickness indicates and why USI is a reliability tool to use. Studies investigating the thicknesses measured of the abdominal wall and lumbar multifidus and the symmetry or asymmetry that have been reported in cricket pace bowlers, will be discussed and compared.

2.6.1 Ultrasound imaging as a measurement tool

Whittaker (2007) describes the place of and need for rehabilitative ultrasound in clinical practice, in her book, “Ultrasound imaging for rehabilitation of the lumbopelvic region – A clinical approach”. RUSI is ultrasound used in rehabilitation of patients with, for instance, low back pain (LBP), where the patient is instructed to perform an isolated muscle contraction and watches it in real-time on the screen for better understanding and feed-forward to perform it correctly. Diagnostic musculoskeletal ultrasound is used to diagnose conditions of for instance tendon, ligament and muscle injuries.

Ultrasound imaging is an accurate, reliable (Koppenhaver et al., 2009) and non-invasive way of evaluating morphology (size, shape and architecture) of muscle and measuring it to report on the morphometry thereof. It also allows the clinician to evaluate the effect of pathology or interventions on a muscle. According to Whittaker et al. (2007), the size of a muscle relates to the force it is capable of exerting, indirectly indicating muscle strength.

2.6.2 Reliability of ultrasound imaging

Koppenhaver et al. (2009) investigated the intra-rater reliability of USI in the measurement of transversus abdominis and lumbar multifidus on the same day and found it to be very high or excellent at 0.96-0.99. Hides et al. (2007) studied the intra-rater reliability of a novice sonographer with eight hours of training and found that the intra-rater coefficient (ICC) assessing muscle thickness of the same image was very high, namely: >0.97. The ICC across three images was fair to high (0.62-0.82) and similar across two days (0.63-0.85). USI has been validated as reliable against magnetic resonance imaging (MRI) in the measurement of lumbar multifidus and transversus abdominis (Hides et al., 2006). Its reliability has also been validated against EMG during voluntary contractions of transversus abdominis, internal oblique and external oblique (Hodges et al., 2003, McMeeken et al., 2004).

2.6.3 Muscles measured at rest and contracted

Muscles may be evaluated at rest or in the contracted state. Kiesel et al. (2008) used USI to assess muscle activation by measuring changes in the muscle during contraction. Richardson et al. (2004) introduced the isolated contraction of transversus abdominis as the “draw-in” maneuver, based on the rationale of clinical experience and evidence that the deep muscle system has a separate control mechanism which exists in healthy subjects, but is absent in the presence of dysfunction. Hodges et al. (2003b) and McMeeken et al. (2004) found the change in transversus abdominis muscle thickness to be the most common measurement to assess muscle activation and Teyhen et al. (2005) supported this to be a valid measurement of muscle activation. These findings were supported by Kiesel et al. (2007) for lumbar multifidus, when EMG values were generated for these two muscles simultaneously and muscle thickness change was representative of muscle activation.

2.6.4 Studies investigating symmetry and asymmetry of the trunk musculature in cricket pace bowlers

2.6.4.1 Asymmetry in internal oblique

In a study of 25 adolescent provincial pace bowlers (14-18 years old), the total as well as the individual thickness of the muscles of the abdominal wall (external oblique, internal oblique and transversus abdominis) on the non-dominant side measured greater than on the dominant side, in bowlers without LBP according to Gray et al. (2015) . Hides et al. (2008) found the internal oblique on the non-dominant side measured thicker in bowlers (mean age 21.2 years) with LBP, but no difference in thickness of transversus abdominis could be measured between sides. Olivier et al. (2013) supported this finding in their study where they investigated side-to-side symmetry in right-handed pace bowlers with a mean age of 21.8 years. It was found once again that internal oblique measured thicker on the non-dominant side at rest, but no difference was found in the thickness of transversus abdominis or external oblique between sides, as described previously in a study of healthy individuals aged 22 to 62 years old by Mannion et al. (2008) or by Springer et al. (2006) in the study including both genders with a mean age of 31.9 years. Hides et al. (2006) also reported a thicker internal oblique measured on the non-dominant side in fast bowlers (mean age 21.3 years), although this was a very small sample size (n=9).

2.6.4.2 Symmetry in transversus abdominis

Bowlers with LBP had a reduced ability to perform the “draw-in” maneuver and could not isolate a contraction of transversus abdominis from the rest of the abdominal muscles, but in asymptomatic bowlers, the transversus abdominis measured symmetrical (Hides et al., 2008). Hodges et al. (2003) supported this finding as bilateral activity of transversus abdominis was reported to have produced optimal stability of the spine. Springer et al. (2006) reported no asymmetry between sides in asymptomatic individuals, as well as no relationship between hand dominance and transversus abdominis asymmetry. Martin et al. (2017) found that the percentage change of transversus abdominis on the dominant side, from rest to the abdominal draw-in maneuver (ADIM), was less compared to the other side, in pace bowlers sustaining non-contact injuries during the season.

2.6.4.3 Lumbar multifidus symmetry

The cross-sectional area (CSA) of lumbar multifidus – as measured by magnetic resonance imaging (MRI) - on the dominant side of elite cricketers, measured greater than on the non-dominant side and the opposite for the internal oblique muscle (Hides et al., 2008). Teyhen et al. (2012) published normative thickness values for muscles of the abdominal wall and lumbar multifidus at rest as well as in the contracted state. Findings from this study, however, indicated that lumbar multifidus measured symmetrically side-to-side in participants without LBP, supporting findings by Hides et al. (1992). Symmetry of the CSA of lumbar multifidus was also found in injury free pace bowlers, whilst bowlers with a smaller non-dominant lumbar multifidus CSA sustained low back injuries (Olivier et al., 2016).

2.7 Summary

The bowling action of the pace bowler is a rotational, asymmetrical action, performed repetitively. The nature of this action may lead to hypertrophy of muscles activated in a specific manner. From the literature, different patterns of muscle morphometry exist in the adolescent pace bowler with and without pain. Asymmetry of trunk muscles have been described as well as the effect of injury on the trunk muscle morphometry and the prediction thereof on potential injury, but studies investigating the relationship between pace bowling performance and trunk muscle stability, strength-endurance and thickness are lacking in the literature as compared to other sporting codes.

CHAPTER 3

Methodology

3.1 Type of study

This is an observational, cross-sectional study.

3.2 Study setting

This study took place at the outdoor cricket nets of the participating schools. Data were collected in March 2017.

3.3 Participants

3.3.1 Source of participants

Pace bowlers between the ages of 13 and 18 years old, playing for their school's A-teams were invited. Directors of cricket at four secondary schools on the West Rand had their A-team coaches nominate uninjured pace bowlers to take part in the study.

3.3.2 Sample selection

The cricket playing male adolescent pace bowling population in the Gauteng West region totals 16 schools, each with four A-teams and on average four pace bowlers per team, totaling approximately 256 players. A sub-group of the population was sampled by invitation and included according to the inclusion criteria.

The sample size was calculated using Cohen's default interpretations, using G Power 3.1.9.2 and a two-tailed design. The power of 0.8 with a medium to large effect size (0.4) was calculated as being 44 participants. The resulting critical t value was 2.02, with a power value of 0.955.

3.3.3 Inclusion and exclusion criteria

3.3.3.1 Inclusion criteria

Adolescent school A-team pace bowlers between the ages of 13 and 18 years old were included in the study. All participants had to be injury free and actively involved in playing cricket at the time of the study. Only male participants were included, in order to create a homogenous group.

3.3.3.2 Exclusion criteria

Participants with previous upper or lower limb surgery or extensive lower back interventions for their age group, e.g. spinal facet infiltrations, were excluded from the study.

3.4 Instrumentation and outcome measures

3.4.1. Bowling performance: ball release speed

Ball release speed was measured using a hand-held radar speed gun (Stalker, ATS, Texas). The radar gun was positioned five to six metres behind the point of ball release, as closely in line with the bowler's upper limb trajectory as possible. The gun was held by the same research assistant during data collection. The assistant stood on the second step of a standard three-step ladder, pointing the gun down the pitch towards the wickets. The error in ball release speed arising from the 30˚ misalignment of the radar gun was calculated by the reading divided by the cosine of the angle (cos30 = 0.866) as described in the Stalker radar gun owner's manual (Stalker)(Stalker). This is a valid and reliable tool used to measure ball release speed in km/h (Petersen et al., 2004, Phillips et al., 2011, Olivier et al., 2015).

3.4.2. Bowling performance: bowling accuracy

Bowling accuracy was measured using a black shade cloth target with scoring zones sewn onto it in white and a horizontal line in red, 50 centimetres off the ground. A maximum of 100 points was scored if the ball made contact with the rectangular zone extending one metre upwards from the horizontal red line (50 centimetres off the ground, thus 20 centimetres lower than the top of off-stump) and 30 centimetres sideways from off-stump (Figure 3.1). The adjacent zone, scoring 50 points, was an inverted capital L to the left of the rectangle. The outer most scoring zone, scoring 25 points, was an inverted capital U. If the ball made contact with the target outside of any of these zones, or missed the target altogether, the bowler was awarded zero. This is a tool utilised to measure accuracy of a delivery and used extensively in bowling studies (Elliott et al., 2005, Portus et al., 2000, Crewe et al., 2013).

Figure 3.1 Accuracy target and hand-held radar gun

3.4.3. Trunk muscle stability

The Sahrmann Stability Scale (Sahrmann, 2002) was used to assess trunk muscle stability. A Chattanooga pressure biofeedback (Encore Medical, Australia) was inflated to 40mm Hg and positioned in the lumbar lordosis with the participant in supine crook-lying. The participant was taught how to perform the “draw-in maneuver” before he was tested.

The participant was positioned in supine, crook-lying. The participant was then instructed to take a breath and flatten the lumbar lordosis into the plinth – pulling the belly-button up and into the spine at a sub-maximal contraction – on expiration (Richardson et al., 2004). The participant was instructed to maintain the “draw-in maneuver” throughout a level, not allowing the spine to move which would result in a pressure deviation of more than 10mm Hg on the pressure biofeedback – an indication of spinal stability lost. The levels are described in Table 3.2. A participant was allowed to proceed to the next level of the Sahrmann Stability Scale if a deviation of less than 10mm Hg was present on the pressure biofeedback. A participant was awarded the level number between one and five of the last level passed on the scale. The intra-reliability coefficient for this test is 0.95 (Stanton et al., 2004).

Table 3.1 The Sahrmann Stability Scale

Level 1	Start in supine, crook-lying position: perform abdominal draw in. Slowly raise 1 leg to 100˚ of hip flexion, knee comfortably flexed. Bring opposite leg up to the same position.
Level 2	From hip flexion position, slowly lower 1 leg until the heel comes into contact with the ground. Slide out the leg to fully extend the knee. Repeat with other leg. Return to starting position.
Level 3	From hip flexion position, slowly lower 1 leg until heel is 12 cm above the ground. Slide out leg to fully extended knee. Repeat with other leg. Return to starting position.
Level 4	From hip flexion position, slowly lower both legs until heels come into contact with the ground. Slide out legs to fully extended knees. Return to starting position.
Level 5	From hip flexion position, slowly lower both legs until heels are 12 cm above ground. Slide out legs to fully extended knees. Return to starting position.

Figure 3.2 Chattanooga pressure biofeedback

Figure 3.3 Sahrmann Stability Scale level 1

Figure 3.4 Sahrmann Stability Scale level 2

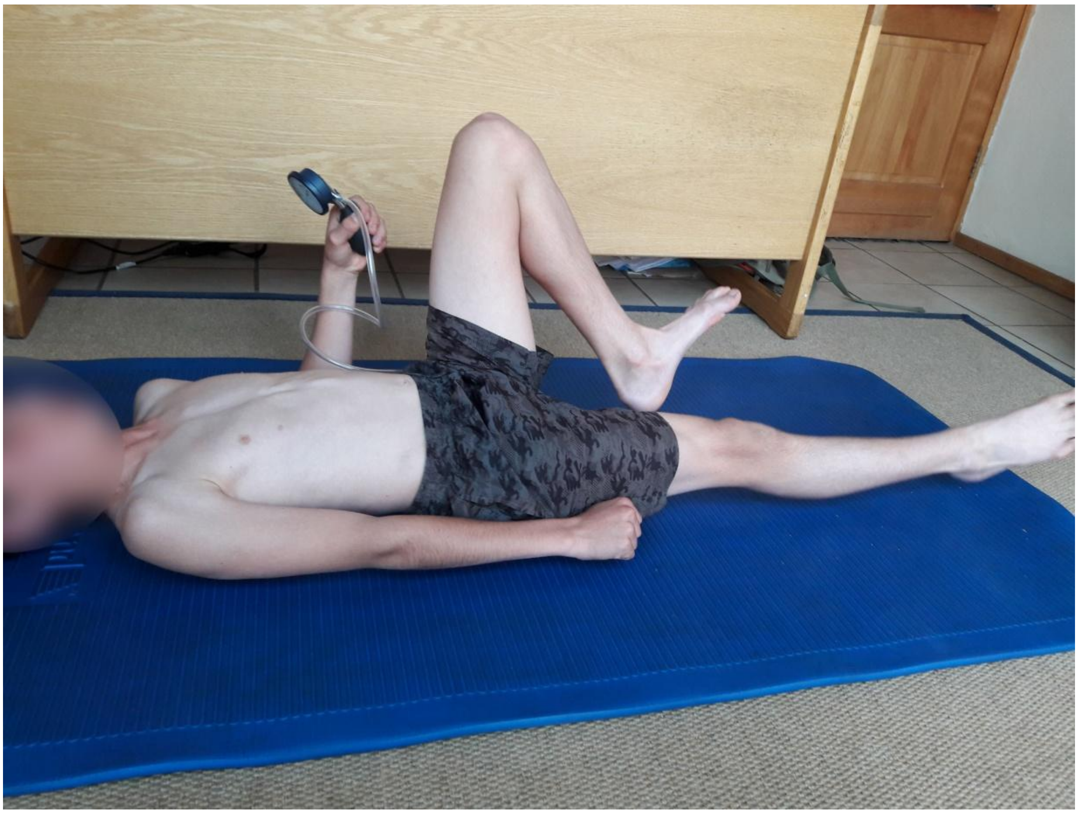

Figure 3.5 Sahrmann Stability Scale level 3

Figure 3.6 Sahrmann Stability Scale level 4

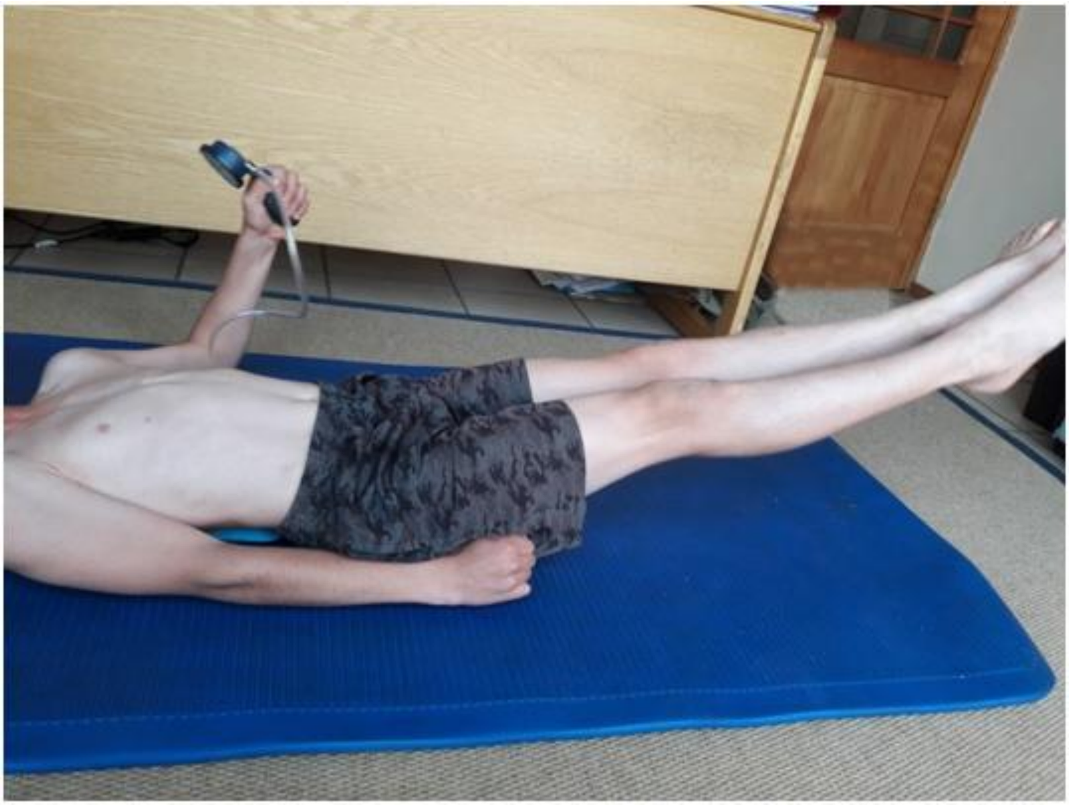

Figure 3.7 Sahrmann Stability Scale level 5

3.4.4. Trunk muscle strength-endurance

The Bourbon Trunk Muscle Strength Test (TMS) (Tschopp et al., 2001, Granacher et al., 2014) was used to assess trunk muscle strength-endurance. The ventral, lateral left and right and dorsal trunk muscle chain tests were performed in randomised order with a 10 minutes recovery time allowed between tests.

3.4.4.1 The ventral trunk muscle chain test

The participant was positioned in bridge, supported on elbows and forefeet on an exercise mat. The glenohumeral joint, greater trochanter and lateral maleolus were located on a straight line for the starting position. A horizontal rod was fixed into contact with the iliac crest. The participant had to remain in contact with the rod, whilst lifting his feet alternatively to the beat of a metronome – one cycle per two seconds - with extended knees, two to five centimetres off the ground. A participant was allowed two warnings if he lost contact with the horizontal rod and the test was terminated on the third warning. The researcher used a stopwatch to record and document time in seconds upon termination of the test. This test is classified as intra-reliable with a coefficient of variation of 14.1% and an r-value of 0.87 on the Pearson test (Tschopp et al., 2001).

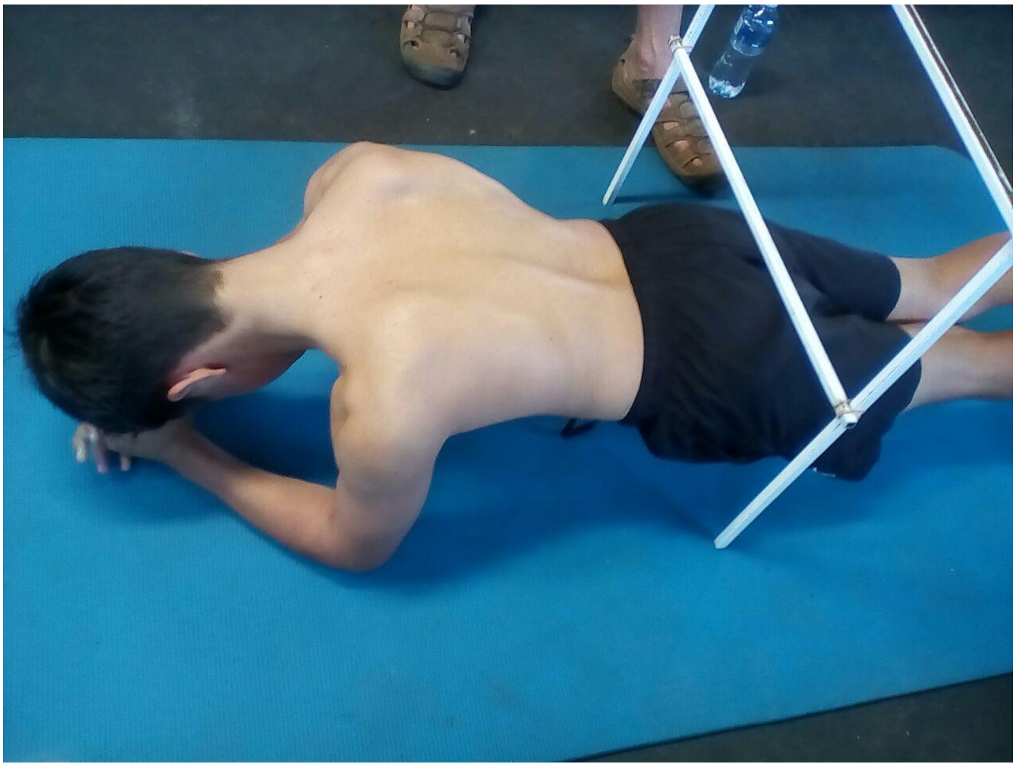

Figure 3.8 Bourbon trunk muscle strength-endurance test for the ventral chain

3.4.4.2 The lateral trunk muscle chain test left and right

The participant was in a side bridge position, legs extended with the upper foot placed on top of the lower one on an exercise mat and the top arm held akimbo. The body of the participant had to be in a straight line from the glenohumeral joint, through to the hips and ankles. In this position, the horizontal rod was fixed into contact with the superior iliac crest. The instruction was to raise the hips into contact with the rod and lower to the mat without unloading the bodyweight. This was done to the beat of a metronome, where the up and down cycle took place in two seconds. Time was recorded with the stopwatch and documented when the test was terminated by the third warning of not touching the rod or on unloading bodyweight onto the mat. This was repeated to the other side after a 10 minutes break. This test is classified as intra-reliable with a coefficient of variation of 14.6% and an r-value of 0.81 on the Pearson test (Tschopp et al., 2001).

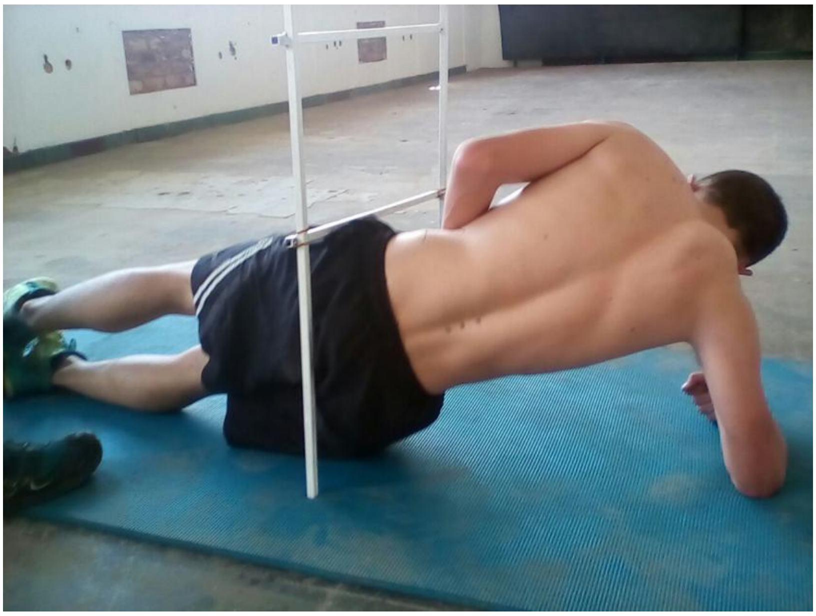

Figure 3.9 Bourbon TMS for the lateral chain right

3.4.4.3 Dorsal trunk muscle chain test

The participant was positioned in prone over the edge of the plinth, supported up to the superior borders of the ilia – hips and calves respectively securely strapped onto the plinth with high tension cargo lock belts. The upper horizontal rod was fixed into contact with a thoracic spinous process with the upper body in neutral (180˚). Using a goniometer, the participant was asked to lower the upper body with arms crossed over the chest and the lower rod fixed at the point where the sternal angle made contact with the rod, at 30˚ trunk flexion. The participant was instructed to raise and lower the upper body to the beat of a metronome – one cycle per two seconds - taking up contact with the upper and lower rods respectively each time. Time was recorded with a stopwatch and documented on termination of the test, which was when the participant failed to make contact with the upper horizontal rod for the third time. According to recommendations regarding absolute reliability by Stokes (1985) this test is classified as intra-reliable with a coefficient of variation of 11.7% and an r-value of 0.8 on the Pearson test (Tschopp et al., 2001).

Figure 3.10 Bourbon trunk muscle chain test for the dorsal muscle chain

3.4.5. Muscle thickness: Ultrasound Imaging (USI)

Muscle thickness of transversus abdominis, external oblique, internal oblique and lumbar multifidus muscle was measured using USI. The researcher underwent training in the use of USI, prior to the pilot study. Measurements were taken in millimeter using a DP-6600 Digital ultrasonic imaging system® (Shenzhen Mindray Bio-medical Electronics Co., Ltd, China) with a 5MHz curvilinear transducer and a large footprint (≥60mm). According to Gray et al. (2015), simultaneous imaging of the transversus abdominis, external oblique and internal oblique takes place and is repeated on the other side.

In standing, the superior borders of the ilia were drawn with a black permanent marker as well as the bilateral inferior border of the rib cage. This distance was measured, halved and marked on the left and right side. This is the position for the probe when taking images of the lateral abdominal wall. The surface anatomy for L4 is the line extending from the superior borders of the ilia, therefore, the spinous process of L4 was marked as well as that of L5.

Participants were instructed to position in crook-lying with their legs over a pillow on the plinth. The ultrasound machine was positioned on a table perpendicular to the plinth, the researcher was sitting on a chair facing the plinth, with the ultrasound to the right. The probe was plugged into brightness mode (B-mode). The abdominal menu was selected. Frequency was set at 6mHz. The F-position selector was turned to the point where the image on screen was horizontally in line with the arrow along the vertical axis. The image of the layers of the lateral abdominal wall had to be in the centre of the screen, with layers parallel to each other before an image was used for measurement. The “draw-in maneuver” (Richardson et al., 2004) was taught to the participants and performed three times to confirm or correct. Performing the “draw-in maneuver”, the participant was lying in supine-crook. Instructions were given to breathe in and on expiration, flatten the lumbar lordosis into the plinth and at the same time pull the bellybutton up and into the spine at a sub-maximal contraction strength (Richardson et al., 2004). Gel was heated in a bottle and kept in a mug with hot water for comfort of the participants.

3.4.5.1 Measurement of thickness of external oblique, internal oblique and transversus abdominis

Participants were lying in supine-crook with a pillow horizontally under the knees. The probe was positioned perpendicular to the skin, taking up good contact on the marked spot. The probe was positioned with the same side pointing to the ceiling every time. The image was taken with the participant completely relaxed, as soon as there was least muscle activity at the end of expiration. With the probe in contact, the participant had to “hold” at the end of expiration and the image was captured and saved under an image number for measurement. The measurement was done with on screen calipers. An “x” would mark the points taken between the starting and end position that had to be measured. Measurement was consistently carried out from the middle of the one fascia layer to the middle of the next layer. This was the method for measuring the thickness of the different muscles of the abdominal wall at rest (Whittaker, 2007). The measurement at rest was done three times on the same side. The “draw-in maneuver” was thereafter performed and on “hold” the image was captured and saved. Measurement was done as above and recorded on the data collection sheet. An assistant documented image numbers on the data collection sheet for each image captured. This was repeated 3 times on both sides at rest as well as in the contracted state for measurement of each muscle of the abdominal wall.

Figure 3.11 Probe position for measurement of abdominal wall right

Figure 3.12 Image of the abdominal wall during the “draw-in maneuver”

3.4.5.2 Measurement of percentage change in muscle thickness of the abdominal wall

Measurement of the muscle thickness was done with on-screen calipers. The researcher took measurements for the individual abdominal layers from the middle of the intermuscular fascia between muscles to the next. The percentage change was then calculated by subtracting the total thickness at rest from the total thickness in the contracted state, divided by the total thickness at rest and multiplying it by 100 (Koppenhaver et al., 2009). The formula is documented under data reduction and analysis.

3.4.5.3 Lumbar multifidus

The participants were lying in prone on a pillow under the hips. The measurement for lumbar multifidus was done on the L4, 5 facet joint left and right, at rest. The marking of these anatomical landmarks was done with the participant in standing when the abdominal wall measurement markings were done. The probe was positioned in the sagittal plane in contact along the spine over the spinous processes. From here, the researcher moved laterally off the spinous processes and over the facet joints to angle the probe approximately 10˚ medially towards the spine. An image of the facet joint could be clearly distinguished and at the end of expiration an image was frozen and saved. Measurement took place using the on-screen calipers from the inferior layer of the sub-cutaneous fat layer to the deepest bony landmark of the facet (Whittaker, 2007). This was repeated 3 times left and right and documented.

Figure 3.13 Probe position for measurement of lumbar multifidus right

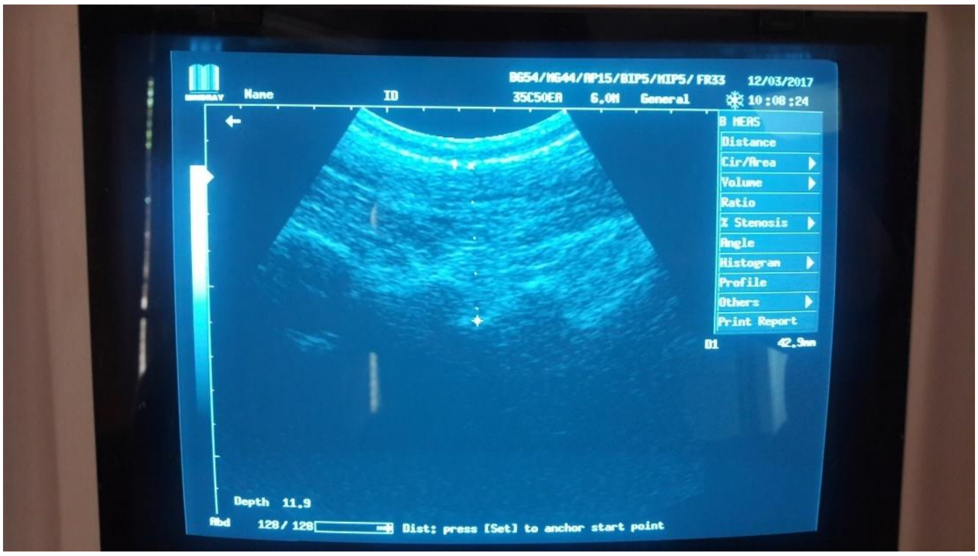

Figure 3.14 Ultrasound image of lumbar multifidus

The criterion-related validity of USI to measure muscle thickness has been established against MRI (Magnetic Resonance Imaging). Intra-rater reliability was established by Springer et al. (2006) as being between 0.93 (95% CI0.86-0.96) to 0.99 (95% CI0.98-1.00) as well as by Rankin et al. (2006) as being 0.98 to 0.99 (95% CI 0.91-1.00), according to Olivier et al. (2013).

3.5 Procedures

3.5.1 Outline of the research process

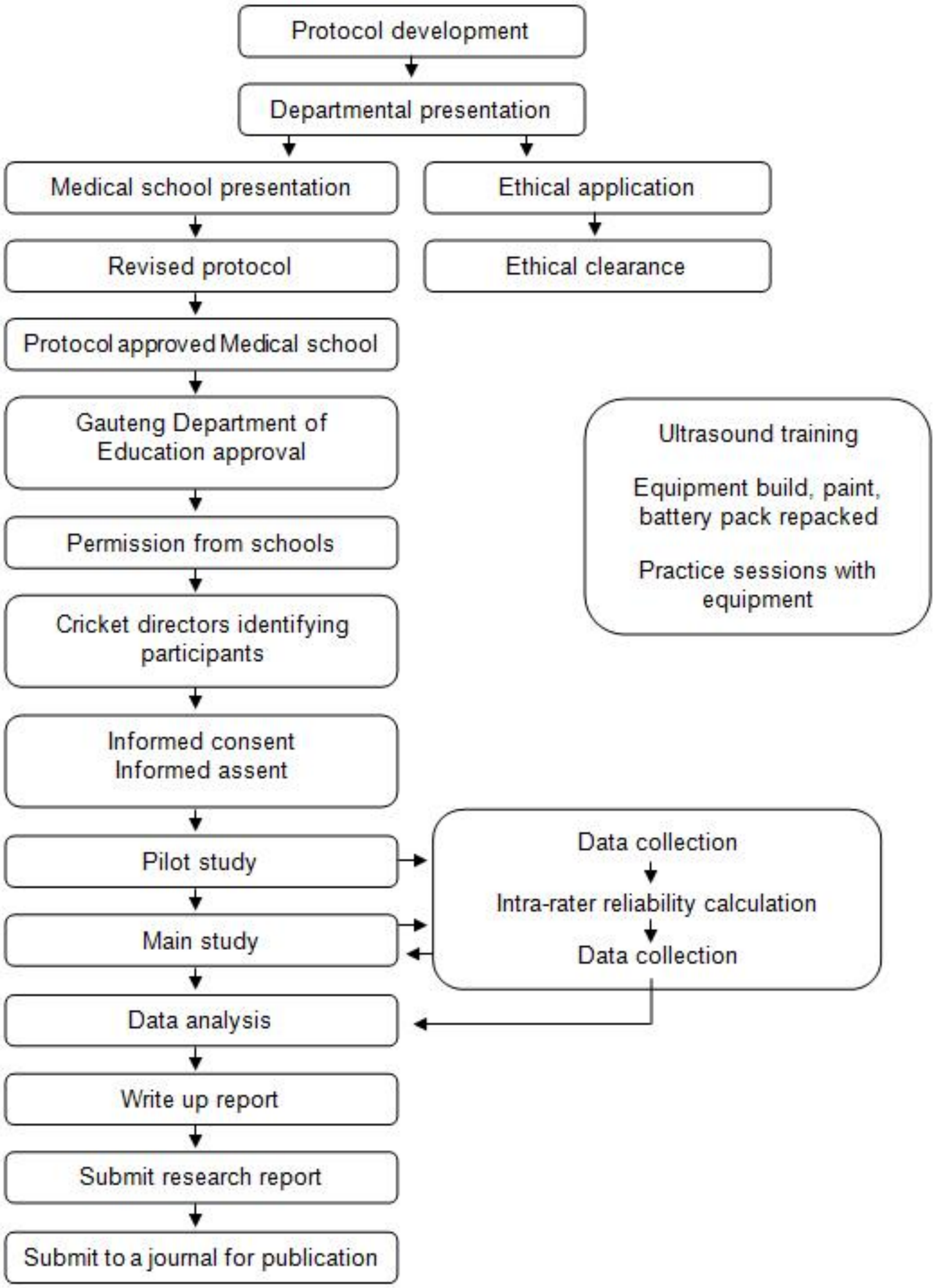

Figure 3.15 Outline of the research process

3.5.2 Pilot study

A pilot study consisted of four participants (10% of sample size) and was conducted to identify potential problems and estimate the time taken to complete the testing. Intra-rater reliability was established by performing tests and measuring all variables twice, an hour apart.

3.5.3 Main study

Ethical clearance was received by the Human Research Ethics Committee of the University of the Witwatersrand (M160852) to perform the study (Appendix A). Permission was granted by the Gauteng Department of Education (Appendix B) to invite players from government schools on the West Rand. Permission was also obtained from individual schools (Appendix C-F) to invite their players and to perform data collection at the respective sites.

Directors of cricket informed the coaches of the respective teams to identify players eligible for taking part in the study. Parents or guardians of the identified players then received an information sheet regarding the study (Appendix G). Parents or guardians then signed the informed consent letter (Appendix H), giving permission for their child to participate in the study. The participant also received a letter of information (Appendix I), compiled by the researcher and signed a letter of informed assent (Appendix J). These signed documents were returned electronically or in hard copy to the researcher and kept on file in hard copy.

Data collection took place at the outdoor cricket nets at Hoërskool Monument, Hoërskool Bastion, Hoërskool Noordheuwel and Krugersdorp High School in Krugersdorp, Gauteng, during the week of 3-7 March 2017.

The venues at the different schools were booked well in advance and participants booked a time slot on the roster for a specific date and venue. Bookings were confirmed telephonically with participants the day before. The ultrasound machine and hand-held radar gun were booked out from the Physiotherapy Department of the University of the Witwatersrand for the duration of the data collection period.

On arrival, participants reported to the researcher and the corresponding study number that was allocated on the participant information sheet was copied to the data collection sheet (Appendix K). The original information sheets were hereafter locked up in a safe to prevent the researcher from identifying participants, as data was documented on the collection sheet. The purpose of the study was explained briefly to a participant on arrival and the radar gun and accuracy target introduced, together with the different stations where tests were going to be performed. Tests were performed in the same order on each participant, except for the individual trunk muscle chain tests of the Bourbon TMS.

Participants had to verbally report on any injuries they had, for which they received treatment or that kept them from taking part in a training session or a match during the previous season, ensuring only participants free of injuries were included in the study. This was done in private, without a parent or coach present, and with the participant aware of the non-disclosure of information as per information sheet provided. Height was measured against a wall with a tape measure stuck up against it. Measurement was marked on full inspiration and documented. Weight was measured bare feet and in a pair of lightweight shorts on an electronic scale and documented on the data collection sheet.

3.5.3.1. Bowling performance

Bowling performance included the measurement of ball release speed and the accuracy of bowling as measured by the block in which the ball made contact on the target behind the stumps. The full run up was measured out by the bowler and marked. The participants were instructed to bowl 6 match pace deliveries, aiming for the top of the wicket on the off-side – or a good length according to Woolmer et al. (2008), as if they were bowling to a right-handed batsman. Each participant was allowed three practice balls to familiarise themselves with the target. A judge facing the target (Figure 3.1) documented the score after each delivery and the speed for that particular delivery was documented on the data collection sheet (Appendix K). An entire over was bowled by one participant, using a white County Premier match ball weighing 156g. The speed and accuracy for each delivery were documented on the data collection sheet.

3.5.3.2. Trunk muscle thickness as measured by ultrasound imaging

Measurement of external oblique, internal oblique and transversus abdominis

The participants had to remove clothing from the upper body (as per information sheet to both parents as well as participants) and ultrasound images were taken with the participants dressed in shorts only. The participant was lying supine on a plinth, with his legs supported over a pillow. The probe was placed in contact with the skin, using heated ultrasound gel - at the position marked as described: halfway between the inferior border of the ribcage and the iliac crest, in the mid-axillary line (Figure 3.11). The participant was instructed to breathe in and hold at the end of expiration to measure the abdominal wall at rest. This frame was frozen, saved and measured as described earlier: each individual muscle layer was measured using the on-screen calipers from the centre of the intermuscular fascia line to the next. Each measurement was taken three times and repeated on the other side. Each measurement was documented on the data collection sheet (Appendix K).

The three muscle layers of the abdominal wall were hereafter measured in the contracted state. The image was frozen, saved and measured once the participant performed the “draw-in” maneuver (Figure 3.12). The thicknesses of muscles of the abdominal wall were measured at rest as well as in the contracted state, in order to calculate the percentage change taking place in these muscles.

Measurement of lumbar multifidus

The thickness of lumbar multifidus was measured at rest only, with the participants in prone and a pillow under the hips (Figure 3.13). The probe was placed over the L4,5 facet joint and the image frozen, saved and measured as described earlier: from the inferior layer of the sub-cutaneous fat layer to the deepest bony landmark of the facet (Figure 3.14). Measurements were repeated three times on each side and documented on the data collection sheet (Appendix K).

3.5.3.3. Sahrmann Stability Scale for measuring trunk muscle stability

The Sahrmann Stability Scale was explained by the researcher and every subsequent level, as the participant passed it. An inflated Chattanoogga Biofeedback device (Figure 3.2) was placed in the small of the back with the participant supine in crook-lying on an exercise mat. The “draw-in maneuver” was known to the participant by now, after having to perform it for the ultrasound measurement. Level 1 (Figure 3.3) was performed as described earlier and each subsequent level (Figure 3.4-Figure 3.7), if the participant managed to avoid a deviation of not more than 10 mm on the biofeedback held in his hand. Each level passed was documented on the data collection sheet (Appendix K).

3.5.3.4. Bourbon Trunk Muscle Strength Test (TMS) measuring trunk muscle strength-endurance

The ventral (Figure 3.8), dorsal (Figure 3.10) and lateral trunk muscle chains left and right (Figure 3.9), as described earlier were tested randomly, with 10 minutes recovery time allowed in between. Time of termination of each test was recorded in seconds and documented on the data collection sheet (Appendix K).

3.6 General considerations

Participants were not expected to perform high risk tests or maneuvers completely unfamiliar to them. Bowling at their school's nets is an activity that a pace bowler performs in his natural environment. No spectators were allowed around the nets during the data collection of the bowling performance, as not to provide external motivation for participants. Bowling an over of six deliveries is far less than their usual bowling load. Therefore, measuring bowling performance of the participants posed no increased risk of injury other that what they are usually exposed to. The tests used in this study are non-invasive measures, posing absolutely no threat to participants and especially the ultrasound was met with enthusiasm. Care was taken to correct participants performing the "draw-in maneuver", as this was important for stability of the back when adding levers of limbs during the Sahrmann Stability Scale. As trunk muscle training might not be an integral part of participants' training programme, muscle soreness could have been experienced afterwards and participants were warned and put at ease about the possibility of experiencing trunk muscle soreness the following day. Personal measurements were made available to participants in sealed envelopes with a brief discussion, stressing the fact that these measurements form a baseline for future measurements, should an individual pursue a cricket career, and that data analysis had not yet been conducted on the raw data, therefore, no conclusions could be drawn at that stage. Bowling technique was not assessed or altered during the data collection, therefore, no changes were present in bowlers' technique after having taken part in the study that could cause a detrimental change in their performance. The researcher also noted deviations in posture, unknown to the participants, and suggested seeking professional help if they posed a potential risk of injury, impaired health, or performance.

3.7 Data reduction and analysis

Data were analysed statistically using GraphPad 5 (Prism, San Diageo, USA). The distribution of the variables was tested using a distributed Shapiro-Wilk test. Descriptive statistics, using means and standard deviations, was performed on all the data collected. Not all variables conformed to normal distribution; therefore Spearman's correlation was performed on those data and Pearson's correlation on normally distributed data.

The following variables were not normally distributed: age, weight, stability, strength-endurance of the ventral trunk muscle chain, dominant external oblique at rest, dominant transversus abdominis at rest, dominant total thickness at rest, dominant percentage thickness change, dominant multifidus, non-dominant external oblique at rest, non-dominant transversus abdominis at rest, non-dominant external and internal oblique contracted and non-dominant percentage change. Variables normally distributed were: height, maximum speed, accuracy, dominant internal oblique at rest, dominant internal oblique contracted, dominant transversus abdominis contracted, dominant total thickness contracted, non-dominant internal oblique at rest, non-dominant transversus abdominis contracted, non-dominant total thickness at rest and contracted, non-dominant multifidus, strength of the dorsal and lateral chains left and right.

Firstly, a correlation was drawn between speed and accuracy. Height, weight and age was also correlated to ball release speed (average and maximum) and accuracy, as well as trunk muscle thickness, using Spearman correlations with statistical significance set at $p<0.05$.

Thereafter, a correlation matrix between the collected variables (maximum speed, accuracy, trunk muscle stability, strength-endurance and thickness) was run. Paired t-tests were used to compare muscle thicknesses of the dominant and non-dominant side for normally distributed data, while Wilcoxon sign test was used for non-normally distributed data. A significance level of $p<0.05$ was set.

The difference in strength-endurance between the dorsal, ventral and lateral trunk muscle chains, measured in seconds, was determined by a one-way analysis of variance followed by a Bonferroni’s multiple comparison test. Qualitative descriptions for the strength of the relationships were based on that described in Portney and Watkins (2009): $r=0.00$-0.25 little or no relationship; $r=0.26$-0.50 fair relationship; $r=0.51$-0.75 moderate to good relationship; $r>0.75$ good to excellent relationship (Portney and Watkins, 2009).

The percentage change of the abdominal wall was calculated by using the measurements as described and applying the following formula by Koppenhaver et al. (2009).

$$\% \text{ change thickness} = \frac{\text{total thickness contracted} - \text{total thickness rest}}{\text{total thickness rest}} \times 100$$

Assymmetry of muscle thicknesses side-to-side, expressed as the percentage difference between the sides, was calculated using the following formula as described by Stokes et al. (2005)

$$\% \text{ difference} = \left(\frac{\text{largest value}}{\text{smallest value}} \times 100 \right) - 100$$

A multiple linear regression analysis was done, using SPSS (version 23) for maximum ball release speed and accuracy as well as bowling performance (the interaction between ball release speed and accuracy – as no co linearity existed between these two dependent variables), using the backward method. For ball release speed, 17 models were created, and the best fitting model used, had an R-square value of .607, suggesting that the statistically significant independent variables in this model explained 60.7% of the variance of the ball release speed. This model was statistically significant, F (7) = 8.378, p<0.001. For accuracy, 21 were created, and the best fitting model had an R-square value of .207, suggesting that the statistically significant independent variables in this model explained 20.7% of the variance of accuracy. This model was statistically significant, F (4) = 2.670, p=0.46. Eight models were created for bowling performance and the best fitting one used had an R-square value of .084, indicating that the statistically significant independent variables in this model accounted for 8.4% of variance in bowling performance. This model was also statistically significant, F (1) = 4.059, p<0.001.

Ball release speed and accuracy were dependent variables while trunk muscle stability, strength-endurance, thickness, age, height and weight were independent variables. The ways used to summarise and statistically analyse the variables are shown in Table 3.2.

Table 3.2 Central tendency, distribution and statistical analysis of data

Objectives	Type of data collected	Analysis
Determine ball release speed – radar speed gun	Continuous, measured in km/h	Mean, median, SD, range
Determine bowling accuracy – zoned target	Continuous, measured 0-100%	Mean, median, SD, range
Determine trunk muscle stability – Sahrmann Stability cale	Categorical, ordinal 1,2,3,4 or 5 points	Wilcoxon sign test
Determine trunk muscle strength-endurance – Bourbon TMS	Continuous, measured in seconds	Dorsal: Paired t-test Ventral: Wilcoxon Lateral left: Paired t-test Lateral right: Paired t-test
Determine trunk muscle thickness – comparing dominant to non-dominant side by USI	Continuous, measured in mm	Non-dominant side: External oblique at rest: Wilcoxon Internal oblique at rest: Paired t-test Transversus abdominis at rest: Wilcoxon Total thickness at rest: Paired t-test External oblique contracted: Wilcoxon Internal oblique contracted: Wilcoxon Transversus abdominis contracted: Paired t-test Total thickness contracted: Paired t-test % change: Wilcoxon Multifidus: Wilcoxon Dominant side: External oblique at rest: Wilcoxon Internal oblique at rest: Paired t-test
		Transversus abdominis at rest: Wilcoxon Total thickness at rest: Wilcoxon External oblique contracted: Paired t-test Internal oblique contracted: Paired t-test Transversus abdominis contracted: Paired t-test

Objectives	Type of data collected	Analysis
		Total thickness contracted: Paired t-test % change: Wilcoxon Multifidus: Wilcoxon
Determine the association between ball release speed and accuracy	Continuous (measured in km/h) vs continuous (measured 0-100%)	Pearson's correlation
Determine the association between bowling performance (ball release speed and accuracy) and trunk muscle stability	Continuous (measured in km/h) and continuous (measured 0-100%) vs categorical, ordinal (1,2,3,4 or 5 points)	Spearman's correlation
Determine the association between bowling performance (ball release speed and accuracy) and trunk muscle strength-endurance	Continuous (measured in km/h) and continuous (measured 0-100%) vs continuous (measured in seconds)	Spearman's correlation
Determine the association between bowling performance (ball release speed and accuracy) and trunk muscle thickness	Continuous (measured in km/h) and continuous (measured 0-100%) vs continuous (measured in millimeters)	Spearman's correlation
<u>Determine the association between bowling performance (ball release speed and accuracy) and trunk muscle stability, strength-endurance and thickness</u>	Continuous (measured in km/h) and continuous (measured 0-100%) vs categorical, ordinal (1,2,3,4 or 5 points), continuous (measured in seconds) and continuous (measured in millimeters)	Spearman's correlation

SD= Standard deviation

3.8 Conclusion of the methodology

Participants were invited from four schools on the West Rand and took part in this study during March 2017. Meetings were conducted with the directors of cricket at the various schools, explaining the study as well as the inclusion and exclusion criteria. Cricket directors understood the protocol that had to be followed and players were nominated for inclusion in the study. Parents and bowlers were contacted, and information sheets circulated. Informed consent and assent was obtained from parents and bowlers for participation in the study. Permission was granted by the principals and dates finalised. Schools were visited, and tests performed on the participants of that particular school on one day. Bowling performance, including speed and accuracy, was measured and the association with trunk muscle stability, strength and thickness drawn by means of statistical analysis.

CHAPTER 4

Results

4.1 Participants

Forty-six male adolescent school A-team pace bowlers from four secondary schools on the West Rand, between the ages of 13 and 18 years (mean±SD: 15.9±1.3), took part in this study. Forty-two bowled right-handed and four bowled left-handed. The mean height of participants was 173.9 (±8.0) cm and the mean weight was 65.0 (±16.8) kg. Participants were all injury-free at the time of data collection as per inclusion and exclusion criteria.

4.2 Results

4.2.1 Intra-rater reliability

Intra-rater reliability for all variables tested was found to be excellent with R-square values ranging between 0.86-1. All variables showed excellent intra-rater reliability.

4.2.2 Bowling performance: ball release speed and accuracy

4.2.2.1 Ball release speed

The participants bowled at a mean of 109.2 (±11.78) km/h as measured with the hand-held radar speed gun.

4.2.2.2 Accuracy

A mean accuracy score of 69.36 (±21.88) % was attained according to the point of impact of the delivery on the target suspended at the batsman's stumps. Higher scores were awarded in a channel closest to the off-stump.

4.2.3 Trunk muscle stability, strength-endurance and thickness

4.2.3.1 Trunk muscle stability

The median value for trunk muscle stability was 3 (range ±1.25) on the Sahrmann Stability Scale.

4.2.3.2 Trunk muscle strength-endurance

Trunk muscle strength-endurance was calculated by measuring the strength-endurance of four trunk muscle chains in seconds, namely: dorsal, ventral, lateral left and lateral right, performing the Bourbon Trunk Muscle Strength Test (TMS). The strength-endurance values are shown in Table 4.1.

Table 4.1 Trunk muscle strength-endurance measurements using the Bourbon Trunk Muscle Strength Test (n= 46)

Variable (seconds)	Mean	Median	SD	Range
Dorsal chain	69.54	67.50	23.09	105.00
Ventral chain	70.09	63.50	27.91	118.00
Dominant lateral	47.7	45.00	15.68	60.00
Non-dominant lateral	49.83	47.50	17.28	73.00

SD – standard deviation

The difference in strength-endurance between the dorsal, ventral and lateral trunk muscle chains, measured in seconds, was further determined. No statistically significant difference was evident between the strength-endurance of the dorsal and ventral trunk muscle chains (mean difference: -0.5435 seconds) or between the dominant and non-dominant lateral trunk muscle chains (mean difference: 2.13 seconds). The dorsal trunk muscle chain measured stronger than the non-dominant (mean difference: 19.72 seconds) as well as dominant lateral trunk muscle chain (mean difference: 21.85 seconds). The ventral trunk muscle chain also measured stronger than both non-dominant (mean difference: 20.26 seconds) and dominant lateral trunk muscle chain (mean difference: 22.39 seconds) (Table 4.2).

Table 4.2 Comparison between strength-endurance of the different trunk muscle chains

Trunk muscle chain comparison	**Mean difference**	**Significance**	**Result**
Dorsal vs ventral chain	-0.5435 seconds	>0.05	No statistically significant difference between dorsal and ventral chain strength-endurance
Dorsal vs non-dominant lateral chain	19.72 seconds	<0.05*	Dorsal chain stronger than non-dominant lateral chain
Dorsal vs dominant lateral chain	21.85 seconds	<0.05*	Dorsal chain stronger than dominant lateral chain
Ventral vs non-dominant lateral chain	20.26 seconds	<0.05*	Ventral chain stronger than non-dominant lateral chain
Ventral chain vs dominant lateral chain	22.39 seconds	<0.05*	Ventral chain stronger than dominant lateral chain
Non-dominant vs dominant chain	2.13 seconds	>0.05	No statistically significant difference between strength-endurance of non-dominant and dominant lateral chain

*indicates statistical significance ($p<0.05$)

4.2.3.3 Trunk muscle thickness

On the non-dominant side, the external oblique at rest was thicker than on the dominant side (p=0.017). The internal oblique on the non-dominant side measured thicker at rest (p=0.001) and contracted (p=0.001) compared to the dominant side. The total thickness of the abdominal wall on the non-dominant side was significantly thicker at rest as well as in the contracted state (p=0.001). No statistically significant difference was found in the contracted transversus abdominis (p=0.981) or lumbar multifidus at rest (p=0.991) between the dominant and non-dominant sides (Table 4.3).

Table 4.3 A side-to-side comparison of trunk muscle thickness (n=46)

Muscle thickness (mm)	**Non-dominant side**		**Dominant side**		
	Mean (SD)	**Median (range)**	**Mean (SD)**	**Median (range)**	**p value**
External oblique at rest		6.7-1.91		6.01-1.66	0.017*
Internal oblique at rest	11.16±2.65		9.43±2.17		0.001*
Transversus abdominis at rest		4.69-1.01		4.88-1.15	0.123
Total thickness at rest	22.55±4.21			20.34-4.08	0.001*
External oblique contracted		6.19-1.93		5.84-1.88	0.155
Internal oblique contracted		12.97-3.37	10.85±2.98		0.001*
Transversus abdominis contracted	7.98±1.66		7.98±1.9		0.981
Total thickness contracted	27.08±5.12		24.58±5.19		0.001*

Muscle thickness (mm)	Non-domnant		Dominant		
	Mean (SD)	**Median (range)**	**Mean (SD)**	**Median (range)**	**p value**
Multifidus	31.04±7.16			31.4-7.54	0.991

* indicates statistical significance (p<0.05); SD – standard deviation

Normally distributed data presented as mean (SD); Skewed data presented as median (range)

The paired t-test for parametric data and the Wilcoxon sign test for non-parametric data

4.2.4 The association between ball release speed and bowling accuracy

In this study, no relationship was established between maximum ball release speed and accuracy of a delivery (r=0.182, p=0.268).

Table 4.4 Correlation between height, weight, age and average and maximum ball release speed and accuracy

	Ball release (BR) speed				**Accuracy**	
	Average BR speed		**Maximum BR speed**			
	r	**p**	**r**	**p**	**r**	**p**
Height	0.527	<0.001*	0.520	<0.001*	-0.047	0.757
Weight	0.516	<0.001*	0.516	<0.001*	0.103	0.496
Age	0.469	<0.001*	0.449	<0.001*	0.154	0.306

*statistically significant (p<0.05); BR – ball release speed

Height showed a positive moderate to good correlation to average (r=0.527, p<0.001) as well as maximum ball release speed (r=0.520, p<0.001). Weight showed a positive moderate to good relationship to average (r=0.516, p<0.001) and maximum ball release speed (r=0.516, p<0.001). Age showed a fair and positive relationship to average (r=0.469, p<0.001) and maximum ball release speed (r=0.449, p<0.001). Ball release speed (both average as well as maximum) increased when height, weight and age increased. Neither height, weight, nor age could be related to accuracy (Table 4.4).

4.2.5 The association between bowling performance – ball release speed and accuracy - and trunk muscle stability, strength-endurance and thickness

The relationships between bowling performance (ball release speed and accuracy) and trunk muscle stability, strength-endurance and thickness of the abdominal wall (external oblique, internal oblique and transversus abdominis) and lumbar multifidus on both dominant and non-dominant sides were determined. These findings are summarised in tables 4.5-4.6.

4.2.5.1 The association between bowling performance and trunk muscle stability

Ball release speed was not significantly correlated to trunk muscle stability (r=0.278; p=0.061) or accuracy (r=0.026; p=0.866), therefore no association could be drawn between bowling performance and trunk muscle stability.

4.2.5.2 The association between bowling performance and trunk muscle strength-endurance

No significant correlation was found between bowling performance - ball release speed and accuracy - and strength-endurance of the trunk muscle chains as shown in Table 4.5

Table 4.5 Correlation between ball release speed and accuracy and trunk muscle strength-endurance

	Maximum Speed (km/h)		Accuracy (%)	
	r	**p**	**r**	**p**
Strength-endurance dorsal chain	0.214	0.154	-0.062	0.682
Strength-endurance ventral chain	0.180	0.230	0.038	0.801
Strength-endurance lateral chain left	-0.099	0.513	0.131	0.385
Strength-endurance lateral chain right	-0.039	0.796	0.078	0.604

*indicates statistical significance (p<0.05)

4.2.5.3 The association between bowling performance and trunk muscle thickness

Non-dominant side

A fair and positive relationship was found between ball release speed and the thicknesses of the non-dominant internal oblique (r=0.323; p=0.028) and transversus abdominis (r=0.543; p<0.001) at rest. In the contracted state, these same muscles (internal oblique and transversus abdominis) showed a fair and positive relation to ball release speed, with a similar p-value of 0.002 and r-values of 0.449 and 0.440 respectively. The total thickness in the contracted state of the non-dominant abdominal wall showed a moderate to good (positive) correlation to ball release speed (r=0.541; p<0.001). A fair and positive relationship between the thickness of lumbar multifidus and ball release speed was found (r=0.445; p=0.002). Bowling accuracy did not correlate to thickness of any of the trunk muscles measured on the non-dominant side (r=-0.270-0.226, p=0.07-0.866). Participants with thicker trunk muscles on the non-dominant side, therefore, bowled faster (Table 4.6).

Dominant side

Thickness of the transversus abdominis on the dominant side at rest, showed a moderate to good (positive) association with ball release speed (r=0.564; p<0.001), whilst the total thickness of the abdominal wall in the same state showed a fair and positive correlation with ball release speed (r=0.359; p=0.014). In the contracted state, the thickness of the internal oblique, transversus abdominis and the total thickness showed a fair and positive relationship to ball release speed, with r-values of 0.361 (p=0.014), 0.468 (p=0.001) and 0.412 (p=0.004) respectively. A fair and positive association could also be drawn between the thickness of lumbar multifidus and ball release speed (r=0.337, p=0.022). Bowling accuracy did not correlate to thickness of any of the trunk muscles measured on the dominant side (r=-0.105-0.169, p=0.228-0.999). Participants with thicker trunk muscles on the dominant side, therefore, bowled faster (Table 4.6).

Table 4.6 Correlation between bowling performance – ball release speed and accuracy - and trunk muscle thickness

Trunk muscle	**Maximum Speed (km/h)**		**Accuracy (%)**	
	r	**p**	**r**	**p**
Dominant external oblique at rest	0.116	0.442	0.001	0.999
Dominant internal oblique at rest	0.266	0.073	0.062	0.685
Dominant transversus abdominis at rest	0.564	<0.001*	0.105	0.487
Dominant total thickness at rest	0.359	0.014*	0.063	0.678
Dominant external oblique contracted	0.131	0.386	0.134	0.375
Dominant internal oblique contracted	0.361	0.014*	0.116	0.444
Dominant transversus abdominis contracted	0.468	0.001*	0.139	0.357
Dominant total thickness contracted	0.412	0.004*	0.169	0.262

Trunk muscle	Maximum Speed (km/h)		Accuracy (%)	
Dominant total abdominal wall % change	0.137	0.364	0.119	0.432
Dominant lumbar multifidus	0.337	0.022*	0.064	0.673
% change dominant internal oblique	-0.105	0.489	-0.091	0.549
% change dominant transversus abdominis	-0.225	0.132	-0.105	0.486
Non-dominant external oblique at rest	0.047	0.756	-0.121	0.424
Non-dominant internal oblique at rest	0.323	0.028*	0.121	0.424
Non-dominant transversus abdominis at rest	0.543	<0.001*	0.180	0.231
Non-dominant total thickness at rest	0.279	0.060	0.064	0.673
Non-dominant external oblique contracted	0.230	0.125	0.178	0.237
Non-dominant internal oblique contracted	0.449	0.002*	0.167	0.268
Non-dominant transversus abdominis contracted	0.440	0.002*	0.151	0.318
Non-dominant total thickness contracted	0.541	<0.001*	0.226	0.131
Non-dominant total abdominal wall % change	0.220	0.141	0.104	0.492
Non-dominant lumbar multifidus	0.445	0.002*	0.127	0.402
% change non-dominant internal oblique	-0.237	0.113	-0.108	0.474
% change non-dominant transversus abdominis	-0.206	0.169	-0.058	0.702

*indicates statistical significance (p<0.05)

Muscle asymmetries were calculated by the difference between the thicknesses of muscles side-to-side. Percentage difference was calculated by multiplying the result of the largest value divided by the smallest value by 100 and then subtracting 100

(Stokes et al., 2005). None of the difference values of the muscle thicknesses correlated with ball release speed or accuracy (Table 4.7).

Table 4.7 Side-to-side differences in trunk muscle thickness correlated to ball release speed and accuracy

Muscle	Maximum ball release speed		Accuracy	
	r	**p**	**r**	**p**
External oblique at rest	0.054	0.720	-0.074	0.627
Internal oblique at rest	0.216	0.150	0.179	0.233
Transversus abdominis at rest	0.032	0.834	0.076	0.615
Total thickness at rest	0.116	0.441	0.195	0.196
External oblique contracted	-0.023	0.880	-0.046	0.764
Internal oblique contracted	0.102	0.502	0.111	0.463
Transversus abdominis contracted	0.013	0.933	0.065	0.669
Total thickness contracted	-0.017	0.911	0.198	0.186
Lumbar multifidus	0.005	0.973	-0.217	0.147

* indicates statistical significance ($p<0.05$)

Age showed only a fair and positive correlation with the thickness of a few trunk muscles of both the dominant (internal oblique contracted and total thickness contracted) and non-dominant (internal oblique contracted, total thickness contracted and percentage change of the abdominal wall) side ($r=0.313-0.452$; $p<0.05$). These afore mentioned trunk muscles, therefore, measured thicker in older bowlers. All trunk muscle thicknesses, excluding non-dominant external and internal oblique at rest as well as percentage change on both sides, showed a fair or moderate (positive) correlation to height, indicating that these muscles measured thicker in taller participants. Weight correlated positively to all trunk muscle thicknesses, excluding percentage change of the abdominal wall on both sides, indicating that heavier bowlers had thicker trunk muscles (Table 4.8).

Table 4.8 Correlation between age, height, weight and trunk muscle thickness

Muscle	Age		Height		Weight	
	r	p	r	p	r	p
Non-dominant external oblique rest	0.033	0.829	0.259	0.082	0.476	<0.001*
Non-dominant internal oblique rest	0.044	0.769	0.255	0.088	0.338	0.022*
Non-dominant transversus abdominis rest	0.165	0.274	0.458	0.001*	0.625	<0.001*
Non-dominant total thickness rest	0.105	0.486	0.348	0.018*	0.540	<0.001*
Non-dominant external oblique contracted	0.250	0.094	0.304	0.039*	0.458	0.001*
Non-dominant internal oblique contracted	0.400	0.006*	0.433	0.003*	0.433	0.003*
Non-dominant transversus abdominis contracted	0.256	0.082	0.457	0.001*	0.561	<0.001*
Non-dominant total thickness contracted	0.452	0.002*	0.563	<0.001*	0.625	<0.001*
Non-dominant total abdominal wall % change	0.361	0.014*	0.215	0.152	0.172	0.253
Non-dominant lumbar multifidus	0.377	0.009*	0.587	<0.001*	0.728	<0.001*
Dominant external oblique rest	0.093	0.541	0.303	0.040*	0.473	<0.001*
Dominant internal oblique rest	0.208	0.166	0.426	0.003*	0.566	<0.001*
Dominant transversus abdominis rest	0.194	0.197	0.539	<0.001*	0.611	<0.001*
Dominant total	0.171	0.255	0.536	<0.001*	0.694	<0.001*

Muscle	Age		Height		Weight	
	r	p	r	p	r	p
thickness rest						
Dominant external oblique contracted	0.182	0.226	0.317	0.032*	0.559	<0.001*
Dominant internal oblique contracted	0.346	0.018*	0.522	<0.001*	0.493	<0.001*
Dominant transversus abdominis contracted	0.286	0.054	0.510	<0.001*	0.565	<0.001*
Dominant total thickness contracted	0.313	0.034*	0.577	<0.001*	0.668	<0.001*
Dominant total abdominal wall % change	0.216	0.149	0.134	0.374	0.037	0.805
Dominant lumbar multifidus	0.194	0.196	0.491	<0.001*	0.695	<0.001*

*indicates statistical significance ($p<0.05$)

4.3 Results of multiple linear regression

A standard multiple linear regression analysis, utilising the backward method, was performed to identify predictors of bowling performance – ball release speed and accuracy. Variables included in the model, were: trunk muscle stability, strength-endurance, trunk muscle thickness as well as age, height and weight, as these variables showed a positive relationship with ball release speed, as well as reunk muscle thickness.

4.3.1 Ball release speed

A significant test, fit for the model was found; ($F(7) = 8.378$, $p<0.001$) with an R-square value of .607 and an adjusted R-square value of .534. This indicated that 60.7% of the variance in the maximum ball release speed could be explained by these predictors.

Table 4.9 Multiple linear regression model detailing predictors of ball release speed

Model	Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	30.924	15.377		2.011	.051	-.205	62.053
Age	2.637	.973	.297	2.711	.010	.668	4.605
ND TrAbd rest	5.133	2.284	.439	2.248	.030	.510	9.756
D IO rest	-1.672	.894	-.312	-1.870	.069	-3.483	.138
D TrAbd rest	4.667	1.694	.452	2.754	.009	1.236	8.097
D EO contracted	-2.405	.940	-.385	-2.560	.015	-4.308	-.503
D IO contracted	.949	.513	.256	1.851	.072	-.089	1.987
Stability	3.570	1.166	.343	3.061	.004	1.209	5.931

ND= Non-dominant TrAbd= Transversus abdominis IO= Internal oblique EO= External oblique

*indicates statistical significance (p<0.05)

Participants' maximum ball release speed increased by 5.133 units for each unit of trunk muscle thickness increase of the non-dominant transversus abdominis at rest. Maximum ball release speed increased by 4.667 units for each unit of trunk muscle thickness increase in the dominant transversus abdominis at rest and by 3.570 units for each unit increase in trunk muscle stability. As age increased by one unit, ball release speed increased by 2.637 units (Table 4.9).

4.3.2 Accuracy

A significant test, fit for the model was found; ($F (4) = 2.670$, $p=0.46$) with an R-square value of .207, and an adjusted R-square value of .129. This indicated that the significant independent variables in this model only explained 20.7% of the variance in the accuracy.

Table 4.10 Multiple linear regression model detailing the predictors of accuracy

Model	Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	258.312	90.237		2.863	.007	76.074	440.550
Height	-1.388	.605	-.511	-2.295	.027	-2.609	-.166
Weight	.766	.291	.589	2.631	.012	.178	1.355
ND_EO_rest	-3.834	1.874	-.329	-2.045	.047	-7.619	-.048
ND_IO_rest	2.550	1.343	.302	1.899	.065	-.162	5.261

ND= Non-dominant EO=External oblique IO=Internal oblique

*indicates statistical significance ($p<0.05$)

Accuracy of a delivery increased by .766 units with an increase of one unit in weight in a participant. A decrease of 1.388 units in accuracy occurred with each one unit increase in height of a participant. The predictor for accuracy of a delivery was, therefore, found to be weight (Table 4.10).

4.3.3 Bowling performance (ball release speed and accuracy interaction)

Ball release speed and accuracy could not be linearly correlated. These variables could therefore, be combined as the term "bowling performance" applying linear regression analysis, because no interaction was found between them i.e. the assumption of collinearity was not breached.

A significant test, fit for the model was found; ($F (1) = 4.059$, $p<0.001$) with an R-square value of .084 and an adjusted R-square value of .064. This indicated that the statistically significant independent variable in this model only explained 8.4% of the variance in the interaction between ball release speed and accuracy.

Table 4.11 Multiple linear regression model of the predictors of the interaction between ball release speed and accuracy

Model	Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	-1840.501	4711.389		-.391	.698	-11335.681	7654.680
Age	596.108	295.872	.291	2.015	.050	-.184	1192.399

*indicates statistical significance (p<0.05)

Age was found to be the only statistically significant predictor of the interaction between ball release speed and accuracy, namely: bowling performance and accounted for only 8.4% of the variance in the dependent variable (Table 4.11).

4.4 Conclusion of the results

Forty-six male adolescent school A-team pace bowlers were tested, and associations drawn in terms of bowling performance and trunk muscle stability, strength-endurance and thickness of their lateral abdominal walls and lumbar multifidus. No correlation could be found between ball release speed and accuracy. Ball release speed and accuracy (bowling performance) did not correlate with trunk muscle stability or strength-endurance, but the ball release speed component of bowling performance correlated positively with trunk muscle thickness. Age, height, and weight correlated positively with average as well as maximum ball release speed, according to Spearman's correlation, but not with accuracy. These same independent variables also correlated positively with trunk muscle thickness.

On the non-dominant side, however, thickness of transversus abdominis and internal oblique at rest as well as in the contracted state, related positively to ball release speed. The bowlers with the thicker transversus abdominis in both states, measured taller and heavier. Older, taller and heavier bowlers bowled faster when a thicker internal oblique and total abdominal wall was measured in the contracted state. A thicker internal oblique at rest correlated with ball release speed in the heavier bowlers. A thicker lumbar multifidus resulted in faster ball release speed in older, taller and heavier bowlers.

On the dominant side, thickness of transversus abdominis and the total thickness at rest correlated positively and moderate to good and fair to bowling speed respectively, and these participants also measured taller and heavier. The dominant internal oblique and transversus abdominis, as well as the abdominal wall on this side had to be contracted to show a fair and positive relationship to bowling speed. The older, taller and heavier participants presented with thicker transversus abdominis as well as total abdominal wall thickness in the contracted state, related positively to ball release speed, whilst age did not play a role in the thicker contracted transversus abdominis on the dominant side. Lumbar multifidus also showed a fair and positive relationship to bowling speed on the dominant side of the taller and heavier bowlers. Symmetry of lumbar multifidus at rest and transversus abdominis was found side-to-side in the contracted state, but was not related to ball release speed.

A multiple regression analysis was performed – including age, height and weight - to predict the independent variables responsible for the variance in bowling performance (ball release speed and accuracy), because ball release speed also correlated positively with trunk muscle thickness. The predictors of maximum ball release speed were found to be the muscle thicknesses of the transversus abdominis at rest, both on the non-dominant and dominant side. Trunk muscle stability – although as standalone variable stability did not correlate with ball release speed, it acted as a suppressor variable - and age were also found to be predictors of ball release speed. Accuracy could not be correlated to any variable in this study, but the predictor of accuracy was found to be the weight of participants, with weight acting as a suppressor variable, indirectly associated with accuracy. Age accounted for a small variation in the interaction between ball release speed and accuracy (bowling performance).

The researcher therefore, found no direct association between bowling performance and trunk muscle stability and strength-endurance. Trunk muscle thickness accounted for the variance in ball release speed and weight accounted for a small variance in bowling performance.

CHAPTER 5

Discussion

5.1 Introduction

The study set out to determine the association between bowling performance (ball release speed and accuracy) and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers. The intra-rater reliability was found to be excellent and can be considered a strength of the study. Individual correlations were drawn between dependent and independent variables to establish the individual association. A multiple regression analysis was performed thereafter, to assess the ability of trunk muscle stability, strength-endurance and thickness, including age, height and weight, to predict ball release speed, accuracy and bowling performance (ball release speed and accuracy interaction).

No direct association between bowling performance -ball release speed and accuracy - and trunk muscle stability and strength-endurance was found. Trunk muscle stability was found to be a suppressor variable in predicting ball release speed. Trunk muscle thickness accounted for the variance in ball release speed and weight for that of accuracy. Age predicted bowling performance.

5.2 Bowling performance: ball release speed and accuracy

The male adolescent pace bowlers in this study with a mean age of 15.9±1.3 years, measured 173.9 (±8.06) cm tall and weighed 64.95 (±16.8) kg. Participants bowled at a maximum speed of 109 (±11.78) km/h. Loram et al. (2005) conducted a study (n=12), on a similar age group (mean age 16.6±0.7 years), bowling at a speed of 105.12 (±6.48) km/h, measuring 182 (±6) cm tall and weighing 64.95 (±16.8) kg. Anthropometric data and ball release speed compared well between the two studies.

Age (r=0.449, p<0.001), height (r=0.520, p<0.001) and weight (r=0.516, p<0.001) showed a positive fair and moderate to good correlation with maximum ball release speed in this study, implying that the older, taller and heavier a bowler, the faster the ball release speed. This supports the findings of Pyne et al. (2005) suggesting that height and weight influence ball release speed in juniors (14.8±1.3 years). Age was found to be a partial predictor of ball release speed in the current study. This is supported by the study performed by Glazier et al. (2000) where the collegiate-age pace bowlers (21±0.9 years), bowled at 113.4 ((±6.84) km/h and the study by Portus et al. (2000) where first-grade pace bowlers (mean age 23.3±3.7 years) bowled at a speed of 115.56 km/h, supporting the notion that age plays a role in ball release speed. Loomba-Albrect and Styne (2009) reported that at the age of 17-19 years old, the total fat free mass is stable, after the sudden increase around the age of 12, and was of the opinion that a participant is at adult height and bone mineral density.

Bowling accuracy in the current study measured 69.36 (±11.78) %, on deliveries of a good line and length, aimed at the top of the off-stump, using the zoned scoring target suspended at the batsman's stumps. Bowling accuracy could not be correlated to trunk muscle stability, strength-endurance or thickness, but weight of a participant accounted for 20.7% of the variance in accuracy. The same target was used by Portus et al. (2000) and the accuracy score compared well to the first two spells in their study, but the bowlers with a larger body composition (not weight per se) bowled less accurately (r=-0.589; p=0.027) .Their first-grade pace bowlers (n=14) were awarded 727/1200 points, resulting in an accuracy percentage of 60.58%. This accuracy target was modified for junior pace bowlers (under -11, under -13 and under -15) by Elliott et al. (2005) in their study assessing bowling performance over different pitch lengths (16 m, 18 m and 20.12 m). The target was extended to the ground, enlarging the scoring grid, instead of having it suspended 50 cm above the ground, which means comparison of the accuracy data is not possible.

5.3 Bowling performance and trunk muscle stability

Participants in this study scored 3 (±1.25) for trunk muscle stability out of a possible 5 on the Sahrmann Stability Scale (Sahrmann, 2002). This measurement was considerably higher compared to that of the male adolescent runners (age 15.5±1.4 years) in the study by Stanton et al. (2004). Stanton et al. (2004) conducted a six-week Swiss ball core training intervention, after which the result of the Sahrmann Stability Scale was 1.75±0.94, comparing lower than that of the adolescent pace bowlers. This could possibly be explained by the limited trunk movement during running versus bowling as Thorstensson et al. (1982) found lumbar multifidus and longissimus to mainly control sagittal plane movements during running and Behm et al. (2009) found the EMG values of external obliques to be less during running compared to curl-ups. Forrest et al. (2016) found lumbar multifidus and erector spinae to activate the greatest during back foot contact and during the ball release phase, which involves trunk flexion, rotation and side flexion towards the non-dominant side. This illustrates that the trunk stabilisers are activated across a greater arc of movement when bowling, compared to running.

No statistically significant association could be determined between bowling performance (ball release speed and accuracy) and trunk muscle stability in the sample of the current study. Portus et al. (2000) supported these finding as they could not correlate trunk muscle stability to bowling performance (ball release speed and accuracy) either, but, they found that the bowlers who scored higher on the trunk muscle stability test, were also bowling with a slightly more bent knee on front foot impact. Bowlers landing on a straight knee at front foot impact have greater forces acting on the lumbo-pelvic region, and should be expected to have developed strong lumbo-pelvic region stability. On the contrary, bowlers landing on a bent knee are believed to have possibly adapted and improved trunk muscle stability, enabling them to use the trunk as a rigid lever to generate ball release speed, instead of an extended knee.

Studies investigating the association of trunk muscle stability and the performance of pace bowlers are lacking, although other sporting codes have investigated the effect of stability training on athletic performance and found stability training of the trunk and lumbo-pelvic region to improve throwing velocity in handball players. Female handball players' throwing velocity at the goals improved after a six week progressive core training intervention (Saeterbakken et al., 2011) and Manchado et al. (2017) supported this finding in their study on 30 male handball players, after a 10 week core training programme. The measure of core strength and stability was the ability of the participants to progress to the more difficult levels of the training programme. This was explained as an improved kinetic chain, allowing for better transfer of energy and possibly improved technique. Their results indicated an improved throwing velocity due to the increase in lumbo-pelvic strength and stability.

The bowling action differs from that of handball, in the sense that bowling has a rhythmical run-up and the trunk chronologically performs extension, thereafter flexion and then rotation and side flexion away from the bowling arm. The elbow also remains extended during the delivery (Bartlett et al., 1996). The overhead throwing action, on the contrary, has a different sequence of movement, i.e. the wind-up (lifting the lead knee compared to the leap into the arm during bowling), stride, arm-cocking, arm acceleration (with a bent elbow compared to the extended elbow in bowling), arm deceleration and follow-through (Sachlikidis and Salter, 2007). Therefore, although both sports are overhead upper limb ball release actions, the trunk musculature functions differently, but trunk stability plays an important role in the release speed of the ball.

In the current study stability could not be positively correlated to bowling performance – ball release speed and accuracy – but it was found to be a predictor - although as a suppressor variable - of ball release speed in this sample size. Ball release speed increased by 3.570 units for each unit increase in trunk muscle stability and accounted for 60.7% of the variance in ball release speed. Hilligan (2008) reported a good relationship between ball release speed and trunk muscle stability in adult (18-35 years old) male indoor pace bowlers, supporting this finding, although the participants in his study were older and performed slightly different stability tests.

No cause and effect between bowling performance -ball release speed and accuracy – and trunk muscle stability could be determined, because it was an observational cross-sectional study. Studies exist negating that an improved athletic performance was a result of improved core stability as reported in swimmers (Scibek et al., 1999) where no improvement in swimming times occurred once core stability improved. Core stability improved in runners after a six-week Swiss ball core stability training intervention, without improving running economy, according to Stanton et al. (2004). The latter study also used the Sahrmann Stability Scale, like the current study.

Haugen et al. (2016) also reported the association between core stability and athletic performance to be debatable, supporting my findings.

5.4 Bowling performance and trunk muscle strength-endurance

Strength-endurance of the four different trunk muscle chains was measured using the Bourbon TMS (Granacher et al., 2014). The dorsal (69.65±23.09 s) and ventral chain (70.09±27.91 s) were the chains of muscles that participants could contract for the longest time – in seconds – before failing and thereafter, without significant difference between the two sides, the lateral chain left (49.83±17.28 s) and right (47.7±15.68 s). Granacher et al. (2014), found the dorsal chain specifically to be the strongest, although strength-endurance of the participants in their study measured higher in terms of time to fail in seconds for the dorsal muscle chain (152.2±98 s). In their study, 27 physically active participants between the ages of 13 and 15 years old were recruited from local sports clubs and the strength-endurance of trunk muscle chains tested before and after chain strengthening intervention programmes on either stable or unstable surfaces. The ventral trunk muscle chain of the pace bowlers in this study were excellent in comparison to the pre-intervention values of the participants in the Granacher et al. (2014) study (65.5±37.0 s), as did the lateral chains, left (non-dominant) (46.5±20.8 s) and right (dominant) (46.9±18.9 s).

Reference values were published for the minimal strength-endurance of the trunk muscle chains of elite athletes by Bourbon et al. (2001) in a study on 254 elite male athletes from an army school, representing 43 different sporting disciplines. The reference values chosen for the minimal strength-endurance of elite athletes were the average minus one standard deviation. The ventral trunk muscle chain strength-endurance resulted in 101 seconds (151.8±50.9), followed by the dorsal chain at 80 seconds (109.7±30.1) and lastly the lateral chain at 50 seconds (88.7±38.4), and again no distinction between left (non-dominant) and right (dominant). The values obtained in the current study compared well to the values from healthy, physically active adolescents (Granacher et al., 2014), except for the dorsal chain where the adolescent bowlers were not as strong. This could possibly be explained because of the repetitive flexion-rotation-side flexion from an extended position during the bowling action (Bartlett et al., 1996). The reference values of the elite athletes from the army school, however, were higher compared to the values of the adolescent pace bowlers in the current study. The outcome could be expected, as these army athletes were older and competing at an elite level. Borghuis et al. (2008) describes core stability and core strength interchangeably, and is of the opinion that strength is part of stability. The findings of this study might find this opinion acceptable, as the same results were found for the non-existent correlation of stability and strength-endurance to bowling performance.

5.5 Bowling performance and trunk muscle thickness

Results of previous studies investigating the trunk muscle thicknesses of cricket pace bowlers of different ages and levels of play, as well as soldiers without low back pain, including the current study's results are depicted in Table 5.1.

Table 5.1 Comparative data of trunk muscle thickness measured by USI

Author	Participants' age (years)	Level of play	EO (mm) D	EO (mm) ND	IO (mm) D	IO (mm) ND	TA (mm) D	TA (mm) ND	LM(mm) D	LM(mm) ND
Olivier et al. (2013)	21.8±1.8	Amateur-premier league pac bowler	7.5±2.1	7.5±2.6	11.9±2.7	15.2±3.4	5.3±1.4	4.9±1.4	-	-
Gray et al. (2015)	14-18	Provincial level (specialist fast bowler)	7.4±1.9	9.0±1.9	12.3±2.2	16.3±2.7	4.1±0.9	4.9±1.4	-	-
Teyhen et al. (2012)	18-35	Active soldiers without LBP	8.0±1.9 (rest)		10.4±2.3 (rest)		3.9±0.9 (rest)		31.1±4.5 (rest)	-
Martin et al. (2017)	13-18	Schoolboy pace bowlers	6.80±2.09	7.02±1.72	10.28±2.68	11.65±2.96	4.65±1.02	4.88±1.21	-	-
My study	13-18	School A-team pace bowlers	5.82±2.02	6.48±1.97	9.43±2.16	11.16±2.64	4.72±1.43	4.55±1.34	31.4±7.54	31.11±4.42

EO= External oblique IO= Internal oblique TA= Transversus abdominis LM= Lumbar multifidus D= Dominant side ND= Non-dominant side mm= millimetre

Thickness of the non-dominant internal oblique and transversus abdominis, and total thickness of the abdominal wall at rest showed a positive fair and good relationship respectively to ball release speed. This was also true of internal oblique, transversus abdominis and total thickness of the abdominal wall in the contracted state. Bowlers with thicker non-dominant trunk muscles (selective) were observed to have faster ball release speeds. On the dominant side, total thickness of the abdominal wall and transversus abdominis at rest, showed a positive fair and good relationship to ball release speed respectively. A fair and positive relationship existed between ball release speed and internal oblique, transversus abdominis and the total thickness of the abdominal wall in the contracted state, again indicating that participants with thicker trunk muscles – selective muscles on the dominant side in this case – had higher ball release speeds. Previous studies investigating trunk muscle thickness in cricket pace bowlers have found similar patterns of morphometry on both dominant and non-dominant sides, but it was related to muscle adaptation due to the repetitive nature of the bowling action (Olivier et al., 2013) and injury prevention (Gray et al., 2015, Olivier et al., 2016, Martin et al., 2017) and not ball release speed per se.

In this study the thickness of abdominal wall muscles related positively to ball release speed. From literature, it is clear that the cross-sectional area of a muscle relates to strength (Hansen et al., 1999). Therefore, if bigger muscles measure stronger, surely the trunk muscles responsible for contraction during the bowling action, will be able to contract stronger and add to the increased ball release speed.

Asymmetries in the thickness of the abdominal wall noted in the participants of this study, compared to previous studies found in the literature. Both external and internal oblique measured thicker at rest as well as in the contracted state, on the non-dominant side of these pain free adolescent pace bowlers. The thicknesses of these muscles were positively related to ball release speed, but the asymmetry per se, could not be related to ball release speed or accuracy. Studies done by Gray et al. (2015), Olivier et al. (2013), Martin et al. (2017) and Hides et al. (2008) also found internal oblique to be thicker on the non-dominant side in pace bowlers without pain. This study also supports the finding of the total abdominal wall measuring thicker on the non-dominant side as done by Gray et al. (2015) and Hides et al. (2008). This could be explained by sport-specific muscle adaptation associated with the repetitive rotational demands of the bowling action inducing hypertrophy due to high loading of the musculature on the non-dominant side due to the bowling action involving trunk flexion and rotation and side flexion towards the non-dominant side during the delivery stride.

Transversus abdominis measured symmetrical in the contracted state, supporting findings by Hides et al. (2008). Predictors of the ball release speed component of bowling performance in this study, were found to be the thickness of transversus abdominis at rest, on both sides, with the non-dominant side predicted an increase of 5.133 ball release speed units for each unit of trunk muscle thickness. The transversus abdominis at rest on the dominant side predicted an increase of 4.667 ball release speed units for each trunk muscle thickness unit increase. In this model, 60.7% of the variation in ball release speed could be explained by the afore mentioned trunk muscles. These data could not be compared to literature as no such studies exist.

The trunk muscles investigated in the current study, not only included the abdominal wall, but also lumbar multifidus due to its role as trunk stabiliser of the lumbar spine. Thickness of lumbar multifidus measured symmetrical side-to-side in this study, and both thicknesses related positive and fair to ball release speed. Symmetry of lumbar multifidus is supported by Hides et al. (1992) in a study on healthy young adults and Olivier et al. (2016), where the cross-sectional area of lumbar multifidus was symmetrical in pace bowlers remaining injury free through a season and those pace bowlers sustaining a non-contact lower back injury during the season had a smaller non-dominant lumbar multifidus. Their conclusion was that a reduced non-dominant lumbar multifidus muscle size may therefore be a precursor of low back injuries in pace bowlers. Hides et al. (2008) found the opposite, but this could possibly be due to the authors using a combined value for erector spinae and multifidus in their study.

Percentage change for the total thickness of the abdominal wall, as well as transversus abdominis and internal oblique individually during the “draw-in” maneuver measured similar, side-to-side according to the formula by Koppenhaver et al. (2009). In the study by Olivier et al. (2013), however, the percentage change of the non-dominant transversus abdominis and internal oblique of premier league bowlers measured higher. It could possibly be explained by the fact that the amateur bowlers are older than the adolescent pace bowlers and more familiar with the maneuver, compared to their younger counterparts who were introduced to this maneuver for the first time during the current study. Percentage change did not correlate to bowling performance and it cannot be related to any studies, because no comparative studies exist.

Accuracy of a delivery could not be related to thickness of any of the trunk muscles; neither that of the abdominal wall, nor lumbar multifidus. The interaction between ball release speed and accuracy (bowling performance) could not be correlated with or predicted by trunk muscle thicknesses either. No literature exists relating accuracy to trunk muscle morphometry and therefore cannot be compared. Accuracy is the component of bowling performance that is strongly correlated with hand-eye coordination (Taliep et al., 2003) and the technique of keeping the eyes on the wicket throughout the delivery (Lillee, 1977) and have been found to be negatively affected by hypohydration due to impaired cognitive function (Devlin et al., 2001).

5.5.1 Correlation of age, weight and height to trunk muscle thickness and bowling performance

Age, weight and height were found to be positively correlated to ball release speed and trunk muscle thickness. Of these three variables, however, age was the variable correlating least with trunk muscle thickness. The bowlers with a thicker internal oblique in the contracted state, bowled faster, but were also older, taller and heavier. This was true for both the dominant and non-dominant side. A thicker lumbar multifidus – both non-dominant and dominant sides - also resulted in greater ball release speeds. Older, taller and heavier bowlers had a thicker non-dominant lumbar multifidus, relating positively to ball release speed. A thicker dominant lumbar multifidus, relating to ball release speed was measured in taller and heavier bowlers, but not necessarily older participants. A thicker transversus abdominis at rest as well as contracted in both sides, resulted in faster ball release speeds and these bowlers were also taller and heavier. A thicker internal oblique on the non-dominant side related with ball release speed in heavier bowlers, but they were not taller, nor older. Therefore, thickness of certain trunk muscles - on both the dominant and non-dominant side - had an effect on ball release speed. In some cases, these bowlers were older, taller or heavier. Apart from the body composition changes – increase in total body fat, increase in fat free mass and increase in bone mineral content – age has a positive effect on muscle strength and neuromuscular coordination (Hansen et al., 1999).

In the study by Olivier et al. (2013), the comparable trunk muscle thicknesses of the amateur premier-league pace bowlers (21.8±1.8 years old), measured thicker compared to the current study. This was also true when compared to bowlers of Martin et al. (2017) (13-18 years old), which were the same age and level of play as the current study. This supports the notion of age, weight and height being some of the confounding factors of bowling performance, supporting the finding of the current study, where ball release speed increased by 2.637 units for each age unit increase. Age was found to be a partial predictor of ball release speed, where 60,7% of the variation in speed could be accounted for by age and the only predictor of bowling performance (analised as the interaction between ball release speed and accuracy), although only accounting for 8.4% of the variance in bowling performance. Phillips et al. (2011) supported the finding of age as predictor of bowling performance, as one could argue that the skill-level of pace bowlers increase with age. The trunk muscle thicknesses of the provincial level specialist bowlers of this age (14-18 years old) (Gray et al., 2015), however, exceeded that of the afore mentioned studies and compared well with the amateur premier league bowlers. This is possibly due to the players specialising in pace bowling and therefore, having been more exposed to higher loads of training and repeating the bowling action more than the bowlers sourced from school teams.

Weight correlated positively with all trunk muscle thicknesses except the percentage change in the sides and was found to be the greatest predictor of variation in bowling accuracy in the current study, although only accounting for 20.7% thereof. Accuracy increased by .766 units for each one unit increase in weight. Pyne et al. (2006) also found body mass to be the primary predictor for the difference in ball release speed between junior and senior bowlers.

Height correlated positively with the same muscle thicknesses as weight, excluding the non-dominant external and internal oblique at rest, but was not found to be a predictor of ball release speed, accuracy or bowling performance in the current study. Pyne et al. (2006), however, found height to be one of the best predictors of ball release speed in juniors.

Age was found to be a predictor of the interaction between ball release speed and accuracy (bowling performance), accounting for only 8.4% of the variance in this dependent variable. Age, height and weight have been positively correlated with ball release speed previously, and in the current study these variables were also positively correlated to trunk muscle thickness. Studies correlating age, height and weight in adolescent pace bowlers with trunk muscle thickness are scarce, and those investigating the association of these variables with bowling performance even more so. It is therefore, extremely challenging to compare literature.

5.6 Correlation between ball release speed and accuracy

Ball release speed and accuracy were not found to be related in this study, supporting findings of Phillips et al. (2011) and Duffield et al. (2009). Phillips et al. (2011) could not positively correlate ball release speed and accuracy across short, good and full deliveries for different skill-level bowlers. The findings of this study negated the statement of Sachlikidis and Salter (2007), that a trade-off exists between speed and accuracy in dominant arm throws, and that this trade-off is absent for performing this same action with the non-dominant side in high-performance under-17 and under-19 cricketers. Beilock et al. (2002), however, found this trade-off to disappear in highly skilled athletes, as the attention to and control of the performance process is not needed like in the initial stages of mastering new performance processes. This speed-accuracy trade off was assessed in expert and novice golfers and the expert golfers performed better under speed instructions, putting on indoor greens, compared to their novice counterparts needing more time to perform accurately. Therefore, although the pace bowlers participating in the current study were all recruited from their schools' A-teams, one should bear in mind that most of these players play at higher levels as well, for instance, district, regional or provincial level. This could possibly be explanatory of the absence of the trade-off between the ball release speed and accuracy in this study, due to the level of expertise of the participants.

5.7 Conclusion of the discussion

In this study, no association was found between ball release speed and trunk muscle stability or strength-endurance, although trunk muscle stability proved to have an indirect association with ball release speed as a suppressor variable predictor. Anthropometric variables (age, height and weight) correlated positively to ball release speed and trunk muscle thickness, suggesting that the older, taller, heavier bowlers had thicker muscles, enabling them to generate more force in the trunk and resulting in faster ball release speeds. Trunk muscle thickness on both sides, however, showed a positive fair to good relationship to ball release speed and thickness of transversus abdominis at rest – on both sides – greatly predicted ball release speed. Accuracy of a delivery could not be positively correlated to trunk muscle stability, strength-endurance, thickness of any of the investigated trunk muscles, age, height or weight. Weight, however, proved to have an indirect association in the form of a suppressor variable, predicting the variation in accuracy. The variation in bowling performance was found to be accounted for by age.

CHAPTER 6

Conclusion and recommendations for future research

6.1 Conclusion based on the objectives of the study

The objectives of the study were to:

Determine bowling performance; including ball release speed and bowling accuracy

The 46 injury free adolescent pace bowlers participating in this study, bowled at a ball release speed of 109.2 (±11.78) km/h with an accuracy score of 69 (±21.88) %. Their ball release speed compared well and a little faster than their age matched counterparts in literature and accuracy measured on the same scoring target, compared well with college-age pace bowlers.

Determine trunk muscle stability

Trunk muscle stability measured at level 3 (range ±1.25), using the Sahrmann Stability Scale, depicting that most bowlers were able to perform up to level three out of the possible five levels of difficulty. These bowlers measured stronger than male runners of the same age, who have undergone trunk muscle stability training. This might be due to the limited trunk movement in running compared to the bowling action and trunk muscles having to stabilise a greater range of movement during the latter movement, hereby strengthening whilst performing the movement.

Determine trunk muscle strength-endurance

The dorsal and ventral trunk muscle chains measured stronger than the lateral chains. No significant difference could be established between the dorsal and ventral trunk muscle chain, nor between the two lateral chains. In general, these findings were supported well by the literature. Where contrasting findings in terms of strength did exist, these could possibly be explained by the difference in load and exposure of the participants.

Determine thickness of the trunk muscles

Thickness of the muscles of the lateral abdominal wall and lumbar multifidus were measured using USI. The non-dominant side of the abdominal wall at rest; external oblique, internal oblique and total thickness measured significantly thicker, whilst no significant difference existed side-to-side between transversus abdominis at rest and contracted as well as lumbar multifidus. Thickness as well as the morphometrical pattern of side-to-side difference in these muscles are supported by literature.

Determine the association between ball release speed and accuracy

No association could be found between ball release speed and accuracy of a delivery in this study. Literature exist to support as well as negate the speed-accuracy trade-off.

Determine the association between bowling performance and trunk muscle stability, strength-endurance and thickness

No association could be found between bowling performance and trunk muscle stability or the strength-endurance of the dorsal, ventral and lateral trunk muscle chains in this study, although trunk muscle stability proved to have an indirect association with the ball release speed component of bowling performance - as a suppressor variable predictor. Thickness of the abdominal wall in both the dominant and non-dominant side correlated positively with ball release speed – at rest and contracted. The thickness of transversus abdominis measured symmetrical side-to-side in the contracted state and thickness of this muscle both at rest as well as in the contracted state related positively to ball release speed. Thickness of transversus abdominis at rest – on both sides – were found to be predictors of ball release speed, together with trunk muscle stability and age. Age, height and weight related positively to both ball release speed and trunk muscle thickness, but not to accuracy of a delivery. The accuracy component of bowling performance was not associated with any of the measured variables in this study, although weight, as a suppressor variable was the only predictor of thereof. Age accounted for the variation in bowling performance.

The findings of this study suggest that the older, taller and heavier adolescent pace bowlers had thicker trunk muscles and bowled faster, but not more accurately than their younger, shorter and lighter counterparts.

6.2 Strengths of the study

The intra-rater reliability for the tests used in this study was found to be excellent. That makes the tests valuable for use in clinical practice and the results can be used to make assumptions like symmetrical lumbar multifidus not only protects the pace bowler, but the thickness of these symmetrical muscle bellies also related to ball release speed. Many studies have investigated the association or effect of trunk muscle stability and strength on athletic performance in other sporting codes or on low back pain, but these data are not necessarily applicable to injury and pain free adolescent pace bowlers. Trunk muscle stability has been associated with ball release speed in adult indoor cricket pace bowlers, but no association could be found in literature between the greater trunk muscle stability scores and bowling performance in first-grade bowlers, supporting the findings of the current study on adolescent pace bowlers.

Ultrasound studies of the trunk muscles - in cricket pace bowlers - have investigated thickness, symmetry or asymmetry, differences in pre- to post-season measurements, differences in participants with and without pain and risk of potential injury. This study, however, investigated the trunk musculature of the injury- and pain free adolescent pace bowler in his natural environment and as a whole – stability, strength-endurance and thickness - in relationship to bowling performance, which make the results applicable to the bowling population of the same age.

6.3 Limitations of the study

Cricket pace bowling is a dynamic action, but the stability test used in this study measured trunk muscle stability on a stable base with only the lower limbs as moving levers. Trunk muscle stability could perhaps be measured by using a more dynamic and sport specific test. The thickness and asymmetry measured on the trunk musculature was done using USI, which is a limiting factor, because the participant is lying supine or prone, and not in a sport-specific weight bearing or dynamic posture, delivering a ball. Electromyography could possibly have been another option to evaluate the activity of the musculature, with the participant performing a delivery. The percentage change was calculated in the abdominal wall, because measurements were taken at rest as well as in the contracted state, but lumbar multifidus was measured only at rest, because the researcher found taking accurate measurements in the contracted state challenging.

The sample size in this study was sufficiently powered to perform correlations. A limited number of variables could be entered into each multiple regression model due to the number of bowlers taking part in this study, as cricket teams only have a limited amount of pace bowlers per team. Also, a larger sample size would have allowed for sub-group analysis within a specific age group or height/weight range.

6.4 Clinical recommendations

Adolescents' bodies are still growing and maturing and therefore, they have the benefit of optimally developing musculature sport-specifically for the sporting code in which they take part. The findings of this study, regarding the specific muscle thicknesses associated with ball release speed, may be generalised to the injury free adolescent pace bowler population. This may be valuable if an adolescent starts developing trunk musculature according to the morphometry patterns found associated with or predicting ball release speed. So, although age, height and weight played a role in ball release speed, perhaps the shorter, lighter, younger bowlers could possibly benefit from specific trunk muscle pattern strengthening to improve ball release speed, because a muscle should become thicker once it is strengthened and against the results of the current study, this could then benefit the bowler in terms of ball release speed.

6.5 Recommendations for future studies

In this observational cross-sectional study, bowling performance could not be associated with trunk muscle stability and strength-endurance, but thickness of the abdominal wall and transversus abdominis were found to be associated with ball release speed, as well as with age, height and weight. The thickness of transversus abdominis on both the dominant and non-dominant side and trunk muscle stability were found to be predictors of ball release speed. A randomised controlled trial investigating the effect of trunk muscle stability and strength-endurance training in the adolescent pace bowler in these specific muscle development patterns on bowling performance, may be beneficial, provided it is performed in age, height and weight matched pairs. If a positive effect is found, a training programme could be developed and implemented to improve trunk muscle stability and thickness and the ball release speed component of bowling performance in this manner.

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APPENDIX A:

Human Research Ethics Committee (Medical)

Clearance Certificate No. M160852

R14/49 Ms Franso-Mari Olivier

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160852

NAME: (Principal Investigator)	Ms Franso-Mari Olivier
DEPARTMENT:	Physiotherapy Maragon Private School West Rand
PROJECT TITLE:	The Association between Bowling Perfomance and Trunk Muscle Stability, Strength and Thickness in Adolescent Pace Bowlers - A Cross-Sectional Study
DATE CONSIDERED:	26/08/2016
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	
APPROVED BY:	Professor P Cleaton-Jones,Chairperson, HREC (Medical)
DATE OF APPROVAL:	23/01/2017

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 in Room 301, 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 August and will therefore be due in the month of August each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date 30/1/2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX B:

Permission letter from Gauteng Department of Education

GAUTENG PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

GAUTENG DEPARTMENT OF EDUCATION
GAUTENG WEST DISTRICT
RECEIVED BY REGISTRY:
2016 -11- 22
08h10
PRIVATE BAG X2020
KRUGERSDORP 1740

MEMO

Enquiries: Denton Viljoen
Directorate: ES (ESS)
Tel: +27 (0)11 693-3681
Fax: +27 (0)11 693-3683
Ref:
Denton.Viljoen@gauteng.gov.za

TO : **FRANSO-MARI OLIVIER**

FROM : **DENTON VILJOEN**
DCES: ESS

DATE : **16 NOVEMBER 2016**

SUBJECT : **The association between bowling performance and trunk muscle stability, strength and thickness in the adolescent pace bowler**

Your request to conduct a cross sectional study in the Gauteng West District relating to the above topic has reference:

We find the title to your impending study quite interesting and we feel honoured that you chose Gauteng West as the District in which to conduct the study. We also hope that the outcome of your study will help to develop and strengthen the sport in our District.

Permission is hereby granted to invite cricket pace bowlers (boys aged 13-18 years old) from Public Ordinary Schools in the Gauteng West District.

Do however take note of the following:

- Although permission is granted by the District Office, the targeted schools should also give their permission. Ultimately, the permission for players to participate in a study such as this should come from the parents.
- Players, parents and educators should always be treated with the utmost respect and professionalism.
- Safety of players is of paramount importance
- We require feedback and confirmation of the schools and the players involved in the study
- We require a full report on the findings and outcomes of your study

We wish you the best of luck with your study and all future endeavours.

Yours faithfully

DENTON VILJOEN	**GIRLIE TWAIBANE**	**OUPA KOAPENG**
DCES: ESS	**CES: ES**	**ACT. DISTRICT DIRECTOR**
DATE: 18/11/2016	**DATE:** 18/11/2016	**DATE** 21/11/2016

District: Gauteng West

Cnr Human & Boshoff Str,
Krugersdorp, 1740
Tel: 011 953 1313 / 011 660 4581
Fax: 011 953 4324

APPENDIX C:

Permission letter from Hoërskool Monument

Hoërskool
Monument
High School

24 November 2016

Aan: Franso-Mari Olivier
Van: Hoërskool Monument

Re: Toestemming om die perseel te gebruik om Monument snelboulers te toets – studie M160852/ Reference number R14/49
Titel: The association between bowling performance and trunk muscle stability, strength and thickness in the adolescent pace bowler – A cross-sectional study
Datum: 24.11.2016

Hiermee gee Hoërskool Monument toestemming dat Franso-Mari Olivier die snelboulers van die 0/13 tot 0/18A-spanne mag toets op die skool se perseel.

GS ENGELBRECHT
KRIEKETHOOF

JSM CALITZ
HOOF

APPENDIX D:

Permission letter from Hoërskool Bastion

AKADEMIES
TEGNO-AKADEMIES
KUNSTEVAKKE
GASVRYHEIDSTUDIES, VERBRUIKERSTUDIES & TOERISME

Hoërskool Bastion

DIE SKOOL WAAR JOU WAARDES VASGELÊ WORD

Aan:	Franso-Mari Olivier
Van:	Hoérskool Bastion
Re:	Toestemming om Bastion se fasiliteite te mag gebruik
Title:	The association between bowling performance and trunk muscle stability, strength and thickness in the adolescent bowler
Studie:	Protocol M160852/ Reference number RI 4/49
Datum:	24.11.2016

Hiermee gee Hoérskool Bastion toestemming dat Franso-Mari Olivier die Hoërskool se fasiliteite vir haar studie mag gebruik.

G.A. KOEKEMOER
HOOF

J.FOURIE

APPENDIX E:

Permission letter from Hoërskool Noordheuwel

Hoërskool
NOORDHEUWEL

KRAG DEUR KENNIS

Bellrylaan
Noordheuwel
1739
Privaatsak x2032
Krugersdorp
1740

Tel: (011) 954 1032
(011) 954 1056/7
Faks: (011) 954 1033
info@nories.co.za
www.nories.co.za

24 November 2016

Aan: Franso-Mari Olivier

Van: Hoerskool Noordheuwel

Re: Toestemming om die perseel te gebruik om Noordheuwel snelboulers te toets – studie M160852/ Reference number R14/49

Titel: The association between bowling performance and trunk muscle stability, strength and thickness in the adolescent pace bowler – A cross-sectional study

Datum: 24.11.2016

Hiermee gee Hoërskool Noordheuwel toestemming dat Franso-Mari Olivier die snelboulers van die 0/13 –0/18 A spanne mag toets op die skool se perseel.

Mnr. Etienne Janse van Rensburg
Krieketorganiseerder

APPENDIX F:

Permission letter from Krugersdorp High School

Krugersdorp High School

SAPIENTIA VINCIT

Cornelius Moll Street, Monument Extension, Krugersdorp
P.O. Box 3031, Kenmare 1745 • Tel: 954-1009 • Fax: 954-3716 • E-mail: admin@khs.gp.school.za • Website: www.khs.org.za

To: Franso-Mari Olivier

From: Krugersdorp High School

Re: Use of KHS premises to conduct the necessary tests on the KHS bowlers relevant to the study: M160852/ Reference number R14/49

Title: The association between bowling performance and trunk muscle stability, strength and thickness in the adolescent pace bowler – A cross-sectional study

Datum: 10/03/2017

Hereby permission is granted to Franso-Mari Olivier to test the bowlers aged u/13 –u/18 at the KHS premises as needed.

N van Blerk
Deputy Head
Extra-Curricular Activities
082 515 1546
nvanblerk@krugerdorphigh.co.za

APPENDIX G:

Information sheet – Parents/guardians

Ethics committee

Information sheet to the parent/guardian

Information document: Parent/ Guardian

Study title: The association between bowling performance and trunk muscle stability, strength-endurance and thickness in the adolescent pace bowler – A cross-sectional study.

Dear Parent/Guardian

My name is Franso-Mari Olivier, and I am an MSc student at the Physiotherapy Department of the University of the Witwatersrand. I am doing research on bowling performance and the trunk muscle stability, strength and thickness. In this study I would like to find out whether the stability, strength or thickness of the trunk muscles has any association with the bowler's bowling performance.

If your child decided to become a participant, measurements will be taken once off and analysed. Your child's' bowling speed and accuracy will be measured, as well as trunk muscle stability, strength and thickness of the involved muscles.

The information could prove valuable for the improvement of pace bowlers' performance if a positive association is found. Coaches could start incorporating specific exercises addressing trunk muscle chain strength and stability, which in turn could prove useful in limiting the incidence of back injuries in the adolescent pace bowler.

Who is eligible to take part in this study?

Adolescent male pace bowlers between the ages of thirteen and eighteen years old, who are playing cricket competitively. Bowlers who have undergone extensive shoulder or back surgery for their age group or who are withdrawn from competing at the time of the study due to injury, will not be allowed to participate.

What is involved in this study?

Testing will take place once off. On the day of testing your child will be required to bowl six match pace deliveries after having warmed up in his own preferred manner. Participants will be required to wear cricket shoes, a pair of shorts and a t-shirt for bowling. The speed of deliveries will be measured by a hand-held radar speed gun and the accuracy by means of two scored zoned targets – one on the pitch and the other behind the batsmen's stumps. An ultrasound will then be taken of your child's abdominal and back muscles during which he will be required to remove his t-shirt. The stability and strength of his trunk muscles will thereafter be tested on an exercise mat, using an inflatable biofeedback monitor and horizontal metal bars. Testing is expected to take up to thirty minutes.

Are there any risks involved taking part in this study?

There are no additional risks involved other than the risks your child is usually exposed to during bowling. If he is not used to regular abdominal and lower back strength training, he might experience delayed onset of muscle soreness of the trunk muscles the following day.

What are the benefits of taking part in this study?

Your child's bowling performance will be measured professionally in terms of bowling speed and accuracy and the results made know to him, would he be interested. The stability and strength of his trunk musculature will be measured by means of valid and reliable tests and the results also available for your perusal. The ultrasound taken of your child's trunk muscles will give you an indication of the activity and thickness thereof and could serve as a baseline for future investigations or conditioning programmes, should he consider pursuing a cricket career. There are no monetary benefits for taking part in this study.

Participation in this study

If he chose to withdraw from the study, I would appreciate it if it was done in writing. Your child is free to withdraw without providing a reason, at any time and without being penalised in any way. No reimbursement will be given to participants other that their measurements made available, if interested.

What will happen if a participant is injured during the study?

The researcher is a registered physiotherapist who deals with sporting injuries on a regular basis and an injury will be assessed immediately, and if needs be, the participant will not be allowed to proceed. A first aid service will also be available on the premises at the time of data collection during the study.

Confidentiality

Efforts will be made to keep personal information confidential, although absolute confidentiality cannot be guaranteed. Each participant will be allocated a study number and names will only appear on consent forms, thereafter data is handled by study number of participants. Information and results are to be used for the purpose of this study only. Reference may be made to the study once the article has been published and referred to by other researchers, but no personal information will be in printed or electronic media. The statistician and researcher will have access to the raw data and data will be stored in a safe place for two years.

For further information, please contact me on 083 3838 179 or send an e-mail to fransomari@gmail.com.

For more information or for reporting ethical concerns, you may contact the chair of the HREC of the University of the Witwatersrand, Prof Cleaton Jones, telephone number: 011 717 2700

Kind regards

Franso-Mari Olivier

APPENDIX H:

Informed consent parents/guardians

Ethics Committee

Informed consent form –Parents/Guardians

Consent form – Parents/Guardians

Study title: The association between bowling performance and trunk muscle stability, strength-endurance and thickness in the adolescent pace bowler – A cross-sectional study

I, __________________ hereby agree that my child__________________________ (name of child) may take part in the study as described to me by the researcher. By signing this from I am allowing him to take part in this study, whereby his bowling performance and trunk musculature will be measured.

I am aware of the fact that he will not be exposed to additional risks other than usually experienced during bowling. I understand that he can withdraw from the study at any time without any repercussions. I also understand that he will not be reimbursed for taking part in this study and confirm that he is doing so voluntarily.

Signature of parent/guardian:____________________Date:___________________

Signature of researcher:

For office use only: Study number:________________

APPENDIX I:

Information sheet – Pace bowler

<u>Ethics Committee</u>

<u>Information sheet to the Pace bowler</u>

Study title: The association between bowling performance and trunk muscle stability, strength-endurance and thickness in adolescent pace bowlers – A cross-sectional study

Dear Pace bowler

My name is Franso-Mari Olivier, and I am an MSc student at the Physiotherapy Department of the University of the Witwatersrand. I am doing research on bowling performance and trunk muscle stability, strength and thickness. Research is just the process to learn the answer to a question. In this study, I would like to find out whether the stability, strength or thickness of the trunk muscles has any association with the bowling performance of participants.

If you decide to become a participant, measurements will be taken once off and analysed. Participants' bowling speed and accuracy will be measured as well as trunk muscle stability, strength and thickness of the involved muscles.

The information could prove valuable to form the basis of future research, establishing cause and effect. Coaches could start incorporating specific exercises addressing trunk muscle stability and strength, which in turn could prove useful in limiting the incidence of back injuries in adolescent bowlers.

<u>Who is eligible to take part in this study?</u>

Adolescent male pace bowlers between the ages of 13 and 18 years old, who are playing cricket competitively. Bowlers who have undergone extensive shoulder, leg or back surgery for their age group or who are withdrawn from competing at the time of the study due to injury, will not be allowed to participate.

What is involved in this study?

Testing will take place once off. On the day of testing, you will be required to bowl six match pace deliveries after having warmed up in your own preferred manner. Participants will be required to wear cricket shoes, a pair of shorts and a t-shirt for bowling. The speed of deliveries will be measured by a hand-held speed radar gun and the accuracy by means of a scored zoned target at the batsman's stumps. An ultrasound will then be taken of your abdominal and back muscles during which you will be required to remove your t-shirt. The stability and strength of your trunk muscles will thereafter be tested on an exercise mat, using an inflatable pressure biofeedback monitor and horizontal metal bars. Testing should take no longer than 30 minutes.

Are there any risks involved taking part in this study?

There are no additional risks involved other than the risks you are usually exposed to during bowling. If you are not used to regular abdominal and lower back strength training, you might experience a level of trunk muscle stiffness the following day.

What will happen if an injury occured during the study?

The investigator is a registered physiotherapist with sound knowledge of injury management and an appointed first aid service will be present during the study to treat any injuries occurring.

What are the benefits of taking part in this study?

Your bowling performance will be measured professionally in terms of bowling speed and accuracy and the results made know to you, would you be interested. The stability and strength of your trunk muscles will be measured by means of valid and reliable tests and the results also available for your perusal. The ultrasound taken of your trunk muscles will give you an indication of the activity and thickness thereof and could serve as a baseline for future investigations or conditioning programmes, should you consider pursuing a career in cricket. There are no monetary benefits for taking part in this study.

Participation in this study

If you choose to withdraw from the study, please do so in writing. You are free to withdraw without providing a reason, at any time and without being penalised in any way. No reimbursement will be given to participants other than their measurements made available, if interested.

Confidentiality

Efforts will be made to keep personal information confidential, although absolute confidentiality cannot be guaranteed. Each participant will be allocated a study number and names will only appear on consent forms, thereafter data is handled by study number of participants. Information and results are to be used for the purposes of the study only. Reference may be made to the study once the article has been published and referred to by other researchers, but no personal information will be in printed or electronic media. The statistician and researcher will have access to the raw data and data will be stored in a locked safe for two years.

For further information, please contact me on 083 3838 179 or send an e-mail to fransomari@gmail.com.

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

Kind regards

Franso-Mari Olivier

BSc. Phys (UF) OMT

APPENDIX J:

Informed assent – Pace bowler (minor)

Ethics Committee

Informed assent form – Minors (Under the age of 18 years)

Consent form: Minor assent form

Study title: The association between bowling performance and trunk muscle stability, strength-endurance and thickness in the adolescent pace bowler – A cross-sectional study

I, ____________________(e-mail address:____ and cell phone number:____________________________) hereby agree to take part in the study as described to me by the researcher and/or my parents. By signing this from I am agreeing to take part in this study, whereby my bowling performance and trunk musculature will be measured.

I am aware of the fact that I will not be exposed to additional risks other than usually experienced during bowling. I understand that I can withdraw from the study at any time without being negatively affected. I also understand that I will not get paid for taking part in this study and confirm that I am doing so out of my own free will.

Signature of bowler:____________________________Date:_______________________

Signature of researcher:

For office use only: Study number:_________________

APPENDIX K:

Data collection sheet

Data collection sheet **Study number:___________**

Left/Right handed____________________Height:_______________Weight:_____________

Please report on any injuries you have sustained (needed treatment for or kept you from playing) during the previous and current season:

____

____

Speed/Accuracy:

	Delivery 1	Delivery 2	Delivery 3	Delivery 4	Delivery 5	Delivery 6
Speed						
Accuracy						

USI: Abdominals

LEFT	**Rest 1**	**Img no**	**Draw-in 1**	**Img no**	**Rest 2**	**Img no**	**Draw -in 2**	**Img no**	**Rest 3**	**Img no**	**Draw-in 3**	**Img 3**
Ext Obliq												
Int Obliq		Xxx		Xxx		xxx		xxx		xxx		xxx
Tr Abd		xxx		xxx		xxx		xxx		xxx		xxx

RIGHT	**Rest 1**	**Img no**	**Draw-in 1**	**Img no**	**Rest 2**	**Img no**	**Draw-in 2**	**Img no**	**Rest 3**	**Img no**	**Draw-in 3**	**Img no**
Ext Obliq												
Int Obliq		xxx		xxx		xxx		xxx		xxx		xxx
Tr Abd		xxx		xxx		xxx		xxx		xxx		xxx

USI: Multifidus

LEFT	**Rest 1**	**Img no**	**Rest 2**	**Img no**	**Rest 3**	**Img no**
xxxxxxxxxxxxxxxxxxxxxx						

RIGHT	**Rest 1**	**Img no**	**Rest 2**	**Img no**	**Rest 3**	**Img no**
xxxxxxxxxxxxxxxxxxxxxx						

Sahrmann Stability Scale Level: 1______2_______3______4_______5________

Bourbon TMS Test:

Ventral chain:_______seconds Lateral chain Left:_________seconds

Lateral chain Right:__________seconds Dorsal chain:__________seconds

APPENDIX L:

Plagiarism declaration

Postgraduate Office, Faculty of Health Sciences
Wits Medical School, 7 York Road, PARKTOWN, 2193, Johannesburg • Tel: (011) 717 2745 • Fax: (011) 717 2119 • e-mail: healthpg@health.wits.ac.za

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I FRANSO-MARI OLIVIER (Student number: 1530325) am a student registered for the degree of MASTER IN PHYSIOTHERAPY in the academic year 2018.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this in not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature: ____________ Date: 14/1/2018

APPENDIX M:

Plagiarism report – Turnitin

Cricket

ORIGINALITY REPORT

%14	%11	%9	%2
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