THE RELATIONSHIP BETWEEN CORE STABILITY AND ATHLETIC PERFORMANCE AMONG FEMALE UNIVERSITY ATHLETES

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DECLARATION

I, Marizanne de Bruin, hereby declare that:

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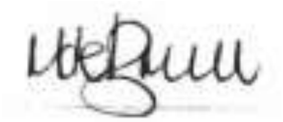

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ABSTRACT

Introduction: Literature on the effect of core stability on athletic performance in different sport codes is limited. Questions remain as to whether core stability should be considered as a component in itself or as different components, as well as the assessment thereof, and if a relationship exists with athletic performance in different sport codes.

Objective: The primary objectives of this research study were to establish an anthropometric profile of female university hockey, netball, running, soccer and tennis athletes and to determine if a relationship exists between core stability and athletic performance.

Population: Data were collected from 83 female athletes from the University of the Free State participating in hockey, netball, middle- and long-distance running (400 m, 800 m, 1 500 m and 3 000 m), soccer and tennis in the 2018/2019 sport season.

Methods: This was a quantitative, cross-sectional study. Core stability was assessed using the isometric back extension (IBE) test, lateral flexion (LF) test and the abdominal flexion (AF) test to assess core strength (in Newton) and core endurance (in seconds), respectively, and the core stability grading system using a pressure biofeedback unit to assess core motor control. Athletic performance was assessed using the forty-metre sprint, T-test, vertical jump and the medicine ball chest throw. All athletes executed three trials of each test in a randomised order and the best value of each test was used for analysis. Correlations between each of the seven core stability tests and the four athletic performance tests were determined, overall, and separately by sport. Furthermore, the effect of core stability on athletic performance assessments was assessed using ANCOVA, fitting the factor of sport, and the covariates age, height, weight, body fat percentage and BMI of the athletes, as well as various interaction terms.

Results: This study depicted the anthropometric profiles of female university athletes and found that runners have the greatest height and netball the greatest body weight, body fat percentage and BMI compared to the other sport codes. Overall, there is a statistically significant difference with respect to age, body weight, body fat percentage and BMI, but height difference is not statistically significant between sports.

The highest mean value for core strength was observed in hockey, whilst tennis showed the lowest, as measured by the IBE, LF and AF characteristics. The highest mean value of core endurance was observed in runners, and the lowest in tennis, as measured by the same characteristics as core strength, only for time. The highest value of core motor control was noted in runners (grade 5) and the lowest in netball (grade 1). The highest average percentage of female university athletes obtained a grade 3. Overall, there is a statistically significant difference in sports with respect to all three characteristics of core strength and core endurance as well as the core motor control component.

When considering the correlations between core stability and athletic performance for all sport codes, all correlations of core strength, core endurance and core motor control with athletic performance were weak ($r<0.2$) and moderately weak ($r=0.2$-0.5). However, when the different core tests were considered separately, the correlations for the LF characteristic of core strength was moderately strong ($r=0.5$-0.8) for the medicine ball chest throw and strong ($r=0.8$-1.0) for the vertical jump.

When considered for the different sport codes separately, moderately strong correlations ($r=0.2$-0.5) were found in all sport codes only- for core strength with certain athletic performance tests. Overall, there is a statistically significant difference between sports with respect to all four athletic performance characteristics.

Conclusion: Correlations were found between core stability and athletic performance, even though some correlations were weak and moderately weak. It can also be concluded that different sport codes require different components of core stability, and have different sets of skills based on the position played and event. Therefore, core stability can be considered as an important modality to improve athletic performance, however, it should not be the main focus in exercise training programmes.

Key words: Core stability, Core strength, Core endurance, Core motor control, Athletic performance, University athletes, Females, Hockey, Netball, Runner, Soccer, Tennis

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LIST OF ABBREVIATIONS

1RM	**One repetition maximum**
AF	**Abdominal flexion**
BF%	**Body fat percentage**
BMI	**Body mass index**
CG	**Control group**
cm	**Centimetre**
CMJ	**Countermovement jump**
CNS	**Central nervous system**
DLLT	**Double leg lowering test**
EG	**Experimental group**
FMS	**Functional Movement Screening**
HSREC	**Health Sciences Research Ethics Committee**
IAP	**Intra-abdominal pressure**
IBE	**Isometric back extension**
ICC	**Intra-class correlation coefficient**
IQR	**Inter-quartile range**
kg	**Kilogram**
$kg.m^{-2}$	**Kilograms per metres squared**
LF	**Lateral flexion**
m	**Metre**
mm	**Millimetre**
mmHg	**Millimetres of mercury**
N	**Newton**
NMC	**Neuromuscular control**
PAS	**Pro-agility shuttle**
Q1	**Quadrant 1**
Q3	**Quadrant 3**
RFD	**Rate of force development**

SBC	**Schwarz Bayesian Information Criterion**
SD	**Standard deviation**
SEBT	**Star Excursion Balance Test**
s	**Seconds**
yr	**Years**

GLOSSARY

Term	Definition
Active muscles	All the muscles responsible for movement of the body
Athletic performance assessments	Sport specific movements including the 40 m sprint to assess speed, T-test to assess agility, vertical jump to assess lower extremity explosive power and the medicine ball chest throw to assess upper extremity explosive power
Biokineticist	An individual in the profession of preventative health care, focusing on the maintenance of physical abilities and final phase rehabilitation, by means of scientifically-based physical activity programmes
Calf	Muscle of the lower leg
Core stability assessments	The components of core stability will be assessed by three core strength tests, three core endurance tests and one core motor control test
Distal	Situated away from the point of attachment
Dynamic	Carrying out movements
Eccentric	The motion of an active muscle whilst it is lengthening under load
Electromyography	The recording of the electrical activity of muscle tissue
Fascia	A band or sheet of connective tissue that separates muscles and other internal organs
Global muscles	Muscles that provide segmental stability and movement or torque generation
Golgi-tendon organs	A proprioceptive sensory receptor organ that senses changes in muscle tension

Iliac crest	Crest of the ilium (largest bone of the pubis)
Iliocristale	Muscle above the iliac crest on the most lateral side
Inguinal fold	The location where the caudal end of the urogenital ridge joins the anterior abdominal wall
Isometric	Contraction where the tension in the muscle increases but the length of the muscle stays the same
Kinetic chain	Joints and segments that have an effect on one another during movement
Local musculature	Stabilising component of muscles
Lumbopelvic-hip complex	Muscles of the lumbar spine, pelvic girdle and hip joint
Motor control	Utilise the brain to activate and coordinate the muscles and limbs involved in the performance of a motor skill
Muscle spindles	A sensory end organ in a muscle that is sensitive to a stretch in the muscle
Musculoskeletal	The muscles in the body and the skeleton considered as one structure
Neutral position	The position of bones and ligaments in such a manner where it allows for optimal movement and minimal stress
Neutral spine	Small range of intervertebral motion near a joint's neutral position where minimal resistance is offered by ligament structures
Omphalion	Midpoint of the navel
Passive structures	The bony structures, ligaments, osseous ligamentous structures, tendons and fascia of the body
Patella	Knee cap
Plyometric	A form of exercise that involves rapid and repeated stretching and contracting of the muscles, designed to increase strength

Pressure biofeedback unit	Blood pressure cuff that changes pressure when detecting movement
Prone	Lying face downwards
Proprioception	The ability to sense stimuli arising within the body regarding position, motion and equilibrium
Proximal	Situated closest to the point of attachment
Runner	Middle- and long-distance athlete participating in either the 400 m, 800 m, 1 500 m or 3 000 m event.
Subscapulare	Skinfold site below the inferior pole of the scapula
Supine	Lying face upwards
Thigh	Muscle of the upper leg
Torque	A force that tends to cause rotation
Tricep	Muscle at the back of the arm
Ultrasound	High-frequency sound waves to produce images of the structures within your body

CHAPTER 1

INTRODUCTION, PROBLEM STATEMENT, AIMS AND OBJECTIVES

1.1 INTRODUCTION

Core strength and core stability have been researched for many years, starting in the 1980s. What is described as 'core' is different in each research study, with most literature involving structures located between the shoulders and hips (Faries & Greenwood, 2007:10). Furthermore, most literature is unsuccessful in differentiating between the two fundamental concepts, namely core strength and core stability (Hibbs *et al*., 2008:996). According to De Blaiser *et al*. (2018:54), more research which includes different groups of athletes and sport codes is needed, and, in addition, the different structures and components that build core stability as a whole should be considered. For the latter to happen, consensus on how these different structures and components could be assessed and defined should be reached. Therefore, core stability assessment should consist of an all-inclusive test battery that evaluates all the components of the core, either in a static or dynamic manner, depending on the demand of the task (De Blaiser *et al*., 2018:54).

The uncertainty with regard to the exact definitions of these two fundamental concepts is to a great extent because these definitions differ greatly and are dependent on the condition they are considered in. In rehabilitation, the emphasis is on physical rehabilitation after injuries have been sustained leading to pathology of the back, arm and leg and allowing the individuals to execute daily tasks, which are low loads, performing exercises that focus on spinal control during loading. This demands a smaller amount of core strength and core stability when compared to the elite sport population participating in sport that requires control of the spine when performing dynamic, heavy weighted and resisted actions (Leetun *et al.*, 2004:926). The anatomical structures involved when performing sport actions and tasks require the whole body to contribute to the movement generated by forces in the body to ensure sufficient sport skills, leading to another explanation of the components of the core. Consequently, there are differences in the definitions of the functional anatomy involved in the core, even though these two fundamental concepts can be explained and defined.

Panjabi (1992:383), explained core stability as a combination of the activation in the passive anatomy of the spine, active muscles of the spine, and the neutral control unit. The latter is responsible for the maintenance of the spinal column range of movement in order for activities to be safely executed throughout everyday activities. Kibler *et al.* (2006:189) summarised the concept of core stability in the sport sector 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 segment in integrated athletic activities”. Akuthota and Nadler (2004:86) define core strength by means of a muscular control unit involved in the maintenance of functional stability around the lumbar spine. This differs from the usual notion of strength when considering the sport sector, as described by Lehman (2006:28), as a maximum force produced by a specific muscle group at a certain velocity. Faries and Greenwood (2007:10) made clearer suggestions for the rehabilitation sector by stating that core stability is the stabilisation ability of the spine, as an effect of muscle activation, whereas core strength refers to the function of the muscles involved to then create force through intra-abdominal pressure (IAP).

It has been suggested by Saeterbakken *et al.* (2011:712) that the core can also be known as the lumbopelvic-hip complex. In this study, the lumbopelvic-hip complex and lumbopelvic core will be referred to as ‘core’. The relationship between core stability and athletic performance has not been clarified up until now. Questions remain regarding the functional aspects of core stability, together with the different demands of sport codes, as well as the assessment of core stability in a functional environment relative to athletic performance (Sharrock *et al.*, 2011:63).

The core consists of 29 muscles attaching to the pelvis, including the spinal column, hip joints and part of the lower extremities (Gamble, 2012:136; Silfies *et al*., 2015:362). Even though the hip musculature attaches to the core and its fundamental role of connecting the lower extremities to the core is noted, Borghuis *et al*. (2008:913) identified that it should not be considered as part of core stability as a whole.

In summary, core stability strengthens the structures that are involved in different sporting movements and we can conclude that no athletic activity is possible without some degree of core stability. Loubser (2018:5) supports this after concluding that a weak correlation exists between core stability and athletic performance in Kovsie male and female first team sports.

Physical performance development can be accomplished through exercise training programmes containing different forms of strength, endurance, agility, speed and explosive power training, thus improving the ability of the athlete to participate in competitions (Reed *et al*., 2012:700). When competing in sport, it requires some form of extremity movement with a certain amount of force to complete the action, placing the body under physical stress (Coetzee *et al*., 2014:39). Therefore, the extremities require a ground contact foundation of support for movement to originate in order for the athlete to perform various sports tasks.

The variation in the demands of the core muscles during activities of daily living (slow movements and low load) and sport tasks (dynamic movements, high load and resistance), lead to a difference between the research conducted for rehabilitation purposes and for the sport sector. Subsequently, research on the topic of core stability exercise programmes and the improvements in athletic performance are limited (Hibbs *et al*., 2008:995).

In conclusion, Hibbs *et al*. (2008:995) found that core stability training programmes, with the aim of improving athletic performance, are beneficial, but a strong scientific evidence of their efficacy is still lacking in the sporting sector. Hibbs *et al*. (2008:995) also concluded that improvement in core stability resulted in improvements in lower back injuries in the rehabilitation sector. A pilot study conducted by Sharrock *et al*. (2011:63) concluded that future research should try to establish the sub-categories involved in core stability and, consequently, identify which are most important to train and perform optimally in individual sport codes. The purpose of this study is to determine if a relationship exists between core stability, which includes the sub-categories of strength, endurance, and neuromuscular control (NMC), and athletic performance among female university athletes.

1.2 PROBLEM STATEMENT

Numerous studies have been performed on core, core stability and core strength, comparing different types of exercises and utilising it as a training modality to decrease the risk of injury, and to incorporate it into rehabilitation to improve athletic performance (Afyon *et al*., 2017:239; Clark *et al*., 2018:1; Dinc & Ergin, 2019:550). However, only limited research produced reliable results to prove that athletic performance improved when training the core in the sporting sector or even prevent injury incidence in the rehabilitation sector (Hibbs *et al.*, 2008:1006). Over the past few years, more attention has been drawn to the function of the core and how it can contribute to enhance sport performance, physical health and fitness, and in reducing the risk of injuries (Granacher *et al*., 2014:2). The aim of research, as conducted up until now, focused on the relationship between core stability and functional movement, and/or to emphasise how training of the core can be combined with an athlete's exercise programme.

Even though several researchers have investigated core stability, none could provide the exact indication for exercise guidelines and programme prescription (Hibbs *et al*., 2008:995; Haugen *et al*., 2016:1; Loubser, 2018:107). Araujo *et al.* (2015:28) indicated that the muscles of the core responsible for stability assist in dynamic tasks in sport and daily living environments. For that reason, it can be seen that the full potential of muscles is used when stabilising the core. Subsequently, the communal topic during the course of the research reflects that athletic performance is influenced by the core (Araujo *et al.,* 2015:28). Nevertheless, suitable methods for assessing core function have not been clarified yet.

Core muscular endurance tests, which assess the ability to hold a specific posture for a duration of time, are often used to assess core stability (Correia *et al*., 2015:311). McGill's core endurance tests, comprising three core tests that involve flexion, extension, and lateral flexion of the spine, are often used as assessment of core endurance (Allen *et al.*, 2014:2063). Nonetheless, there are few studies that have published on the relationship between assessments of core endurance and athletic performance (Sharrock *et al.,* 2011:63). Nesser *et al.* (2008:1750) confirmed weak or moderate correlations between McGill's tests and athletic performance tests, including agility, speed and jump tests. Sharrock *et al.* (2011:63) also indicated that no relationship was found between the double leg lowering test (DLLT), considered as a typical test to assess core endurance, and athletic performance in university athletes of both genders. Subsequently, the relationship between core endurance tests and athletic performance tests is still uncertain and the question needs to be raised whether tests for stability (local and global) will correlate with performance that is related to strength and power of the mobiliser muscle function.

No single gold-standard measurement is described or suggested to evaluate or determine core stability (Brukner & Khan, 2017). This is to be expected as the predominant neuromotor characteristics of the local musculature differ from the more phasic global muscles. Techniques frequently used by investigators in core stability studies include electromyography, isometric endurance testing and ultrasound imaging (Brukner & Khan, 2017). However, Loubser (2018:108) also recommended that "future researchers should seek to identify a golden standard test or battery of tests that quantifies core stability as it pertains to athletic performance, as well as to examine the specific functions of the core, such as endurance, strength and stability, separately, to determine how important each of them are".

Due to the lack of reliable and valid test batteries to measure core stability, there is no evidence that proves that core stability will enhance athletic performance. Athletes and athletic coaches use different core modalities to ensure optimal performance. For that reason, and as part of ongoing research in our Exercise and Sport Science Centre, the main purpose of this study is to evaluate the various components of the core in the assessment of core stability with the aim to determine if a relationship exists between core stability and athletic performance and how core stability should be emphasised during the prescription of exercise training programmes.

1.3 AIM OF THE STUDY

The primary aim of the study is to determine the relationship between core stability and athletic performance among female university athletes.

1.4 THE OBJECTIVES OF THE STUDY

In order to accomplish the aim of the study, the objectives of the study are to:

- Provide an updated literature review on all aspects of core stability and athletic performance.
- To establish an anthropometric profile of female university hockey, netball, runners, soccer and tennis athletes.

- Objectively determine whether core strength, endurance and motor control correlated with athletic performance and body measurements in female athletes. Core stability assessment includes core endurance and core strength tests (Bering-Sorensen isometric back extensor test, abdominal flexion test and lateral flexion test) (Saeterbakken *et al.*, 2015:56), and a core motor control test (Wisbey-Roth Core Stability Grading System using the pressure biofeedback unit) (Wisbey-Roth, 1996). Athletic performance assessment uses four performance tests (T-test assessing agility, 40 metre sprint assessing speed, and vertical jump and medicine ball chest throw assessing lower body and upper body explosive power, respectively) (Sharrock *et al.*, 2011:63).

- To assess whether core strength, endurance and motor control correlated with athletic performance and body measurements differently between the various sport codes.

1.5 SIGNIFICANCE OF THE STUDY

This research project will provide valuable information to different female sport codes regarding test batteries to determine core stability. The results will also provide significant benefits for biokineticists in practice regarding rehabilitation, coaches involved in programme prescription, and athletes' knowledge regarding core stability training to optimise sport performance.

1.6 STRUCTURE OF THE DISSERTATION

This dissertation consists of seven chapters, which are structured as follows:

- **Chapter 1:** The introduction, problem statement, aims and objectives
- **Chapter 2**: Literature review: The relationship between core stability and athletic performance among female university athletes
- **Chapter 3:** Methodology

- **Chapter 4:** Results
- **Chapter 5:** Discussion of results
- **Chapter 6:** Summary, conclusions, limitations and recommendations
- **Chapter 7:** Reflection of the researcher during the research process

Refer to Figure 1.1 for a systematic illustration of the research process.

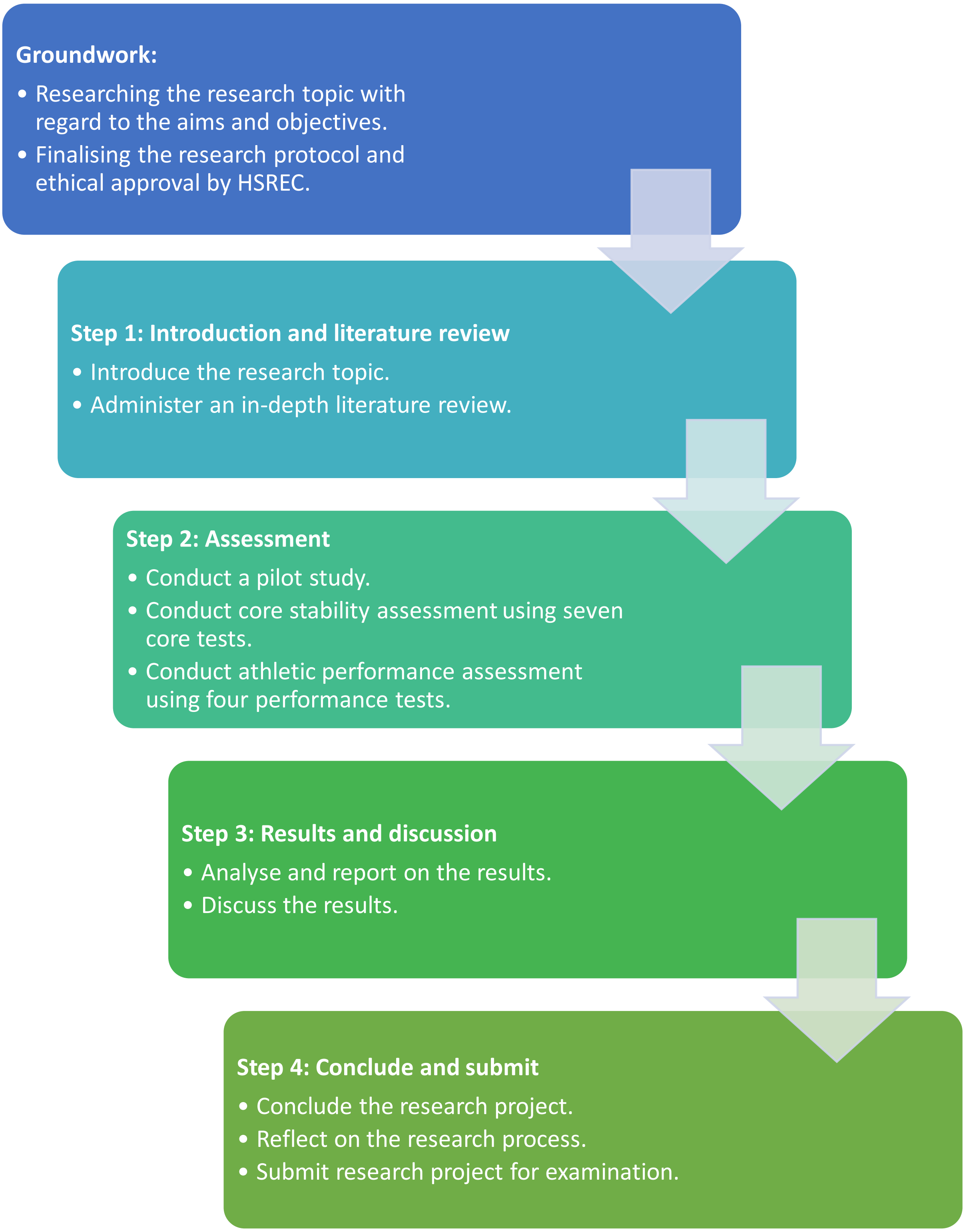

Figure 1.1: Systematic illustration of the research process

CHAPTER 2

LITERATURE REVIEW: THE RELATIONSHIP BETWEEN CORE STABILITY AND ATHLETIC PERFORMANCE AMONG FEMALE UNIVERSITY ATHLETES

2.1 INTRODUCTION

As has been noted, most literature is unsuccessful in differentiating between the two fundamental concepts of core strength and core stability (Hibbs *et al*., 2008:996). It is assumed that a strong core enables the athlete to completely transfer forces produced in the legs, through the trunk, and to the shoulders and arms (Nesser & Lee, 2009:22). In contrast, it is assumed that a weak core disturbs the energy transfer, which then affects athletic performance and possibly increases the risk of injury. Evidently, it can be hypothesised that improvement in core stability leads to improved athletic performance. Hence, training of the core has become common among coaches to enhance performance as well as to reduce the risk for injuries (Nesser *et al.*, 2008:1750). However, Leetun *et al*. (2004:926) reported that core strength, and not core endurance, is a better indicator for the risk of injury in the athletic population and, therefore, training should emphasise the various concepts of the core.

For the last few decades, the term 'core stability' has come to be common in health, fitness and professional sports. Many studies have provided various definitions of core stability, but the dynamic nature of sport complicates the process of evaluating the effects of core stability in these aforementioned fields, as there are currently only static measures for the assessment of core stability (Shinkle *et al*., 2012:373). The high demands of athletic performance on an athlete's body is challenging to duplicate in a static environment only. The core muscles are accountable for supporting the extremities during the movement of forces. In the athletic sector, almost all activities require the movement of forces through the body and, therefore, strong core muscles. To support the latter, Afyon *et al*. (2017:239) suggested that functional sport-specific movements should be used to assess the core in order to determine associations with athletic performance. Whilst only small associations between sprinting and jumping performance and several core strength variables, such as trunk flexion, extension, lateral flexion or rotation, have been described (Shinkle *et al.*, 2012:373), the significance of the core musculature can be reasonably concluded (Wirth *et al.*, 2017:402).

According to McGill (2010:33), the term 'core stability' has no clear meaning and is comprised of the lumbar spine, the abdominal wall muscles (m. external oblique, m. internal oblique, m. transverse abdominis and m. rectus abdominis), the extensors of the lower back (m. erector spinae, m. gluteus maximus and m. quadratus lumborum). Moreover, the multi-joint muscles, namely m. latissimus dorsi and m. psoas, which passes the core, connecting it to the shoulders, arms, pelvis and legs, are also involved. A more compound viewpoint contains the muscles located between the upper extremities and the pelvis (McGill, 2010:33). Another definition of the core, provided by Nelson (2012:34), was the classification of the local and global structures. The position of the core muscles and origin and insertion site determine to which of these two structures it belongs. The local muscles (m. multifidus, m. transverse abdominis) are located deep to support the spine during movement. The global muscles (m. rectus abdominis, m. erector spinae, m. external oblique) are superficially located to function as stabilisers and mobilisers during movement.

It is notable that the term 'core stability' became a popular concept, however, no single definition has been established thus far and many terms and synonyms have been used to denote this concept (De Blaiser *et al.*, 2018:54). Furthermore, differences exist in assessment techniques, outcome measures and the athletic sectors and, to date, researchers have been unsuccessful in providing evidence of the functional and dynamic nature of the core.

2.2 FUNCTIONAL STRUCTURES OF THE CORE

The augmented knowledge of functional core stability has led to the evolution of numerous systems to classify and define the different roles and components that have an impact on core muscle function for dynamic stabilisation (Bliven & Anderson, 2013:515). The adjacent anatomy is imperative for core stability, with the main focus on rehabilitation for injury prevention programmes. The role of core muscles is dependent on its morphological structure, which includes the structural characteristics of muscle fibre size and organisation (Fragala *et al.*, 2015:645).

The functional nature of the core is considered as the coordinated activation of the agonist and antagonist muscles (Stokes *et al*., 2011:797). The agonist muscles are responsible for the movement of the core (flexion, extension, lateral flexion and rotation) and the activation of the antagonist muscles leads to an increased stiffness and, consequently, stability (Stokes *et al*., 2011:797). The main thought of the functional anatomy of the core is that the changes in IAP result in more or less stiffness of the active core muscles surrounding the spine (m. erector spinae and m. gluteus maximus). Whilst all these structures have been proven to play a role in functional and dynamic stabilisation, it is unknown if they directly affect movement and whether they are that important in athletic performance.

2.2.1 Agonist and antagonist muscles

The beginning of a muscle contraction determines the level of stability of the core (Hodges & Moseley, 2003:361). The activation of the m. transverse abdominis leads to activation of the agonist muscles (m. deltoid, m. rectus femoris and m. gluteus maximus), which then results in movement of the upper and lower extremities through a feed-forward mechanism. On the other hand, a delay in the activation of the m. transverse abdominis could lead to a dysfunction in the coordinated activation of the agonist and antagonist muscles which could impair movement and increase the risk of lower back injuries (Wada *et al*., 2018:285-286). Stokes *et al*. (2011:797) declare that the antagonist muscle, m. multifidus, needs only a slight increase in activation to tighten the spinal segments to ensure stability during functional movements.

It can therefore be suggested that the feed-forward mechanism secures the functional stability of the spine and initiates the agonist and antagonist muscles to function in order for movement to occur. Many studies have reported the effect of the feed-forward mechanism by observing the reaction time of agonist muscles in individuals with low back pain, but not in the healthy population and athletic sector (Wada *et al*., 2018:286).

2.2.2 Abdominal wall muscles

The abdominal wall muscles (m. external oblique, m. internal oblique, m. transverse abdominis and m. rectus abdominis) serve mainly as stabilisers of the lumbar spine. In addition, the activation of these muscles results in an increased IAP, and, as a result, controls the loads in the spine (Coulombe *et al.*, 2017:71). The m. multifidus and m. transverse abdominis are the main generators of IAP, and when activated, form a cylinder that increases core stability before movements of the extremities occur (Stokes *et al.*, 2011:797). The m. external oblique eccentrically control the spine during lumbar extension and twisting movements whereas the m. rectus abdominis causes trunk flexion and also braces the spine during high load activities, such as lifting or pushing, due to its high recruitment threshold (Hibbs *et al.*, 2008:998).

Faries (2007:10) explained the concept of abdominal wall hollowing as the synchronised activity of the abdominal wall muscles. When performing abdominal wall hollowing, the activation of the abdominal wall muscles pulls the abdominal wall in toward the lumbar spine, eliminating pelvis movement. Urquhart *et al*. (2005:144) found increased muscle activity of the m. transverse abdominis when performing abdominal wall hollowing, which could be related with good core stability. However, abdominal wall hollowing has not yet been assessed in a functional manner to determine if it can also relate to the functional nature of the core, which includes movement of the pelvis.

Nevertheless, the abdominal wall muscles have been proven to play a role during functional movements as well. Kulas *et al*. (2006:384) researched the effect of abdominal wall muscle activation on landing technique and observed increased IAP right before contact with the ground is made. Atkins *et al*. (2015:1614) found that, in swimmers, the anterior abdominal wall muscles (m. rectus abdominis) are highly involved in the alignment of their posture in the water to prevent them from dragging.

Previous research has investigated training of the abdominal wall muscles and found that the progression of abdominal wall muscle activity is based on the type of exercise performed (Calatayud *et al*., 2017:694). The suspension prone plank and roll-out plank exercises were found most effective to activate the abdominal wall muscles, whereas the suspension lateral plank exercises mostly activated the muscles of the lumbar region (Calatayud *et al*., 2017:694). Therefore, the selection of exercises is important to ensure the correct muscles are trained, however, these exercises are not functional or dynamic enough in nature to replicate sport-specific movements.

2.2.3 Neuromuscular function

It is broadly believed that neuromuscular function is the reason for different muscle reaction times (Wada *et al*., 2018:291). Even though the exact mechanism responsible for neuromuscular function changes is still unknown, it is assumed that the central nervous system (CNS), movement speed of motor neurons, and the reflexive control are a few of the factors leading to this mechanism. An improvement in neuromuscular function, as an effect of the CNS, directly affects the reaction times of muscles and, consequently, the movement of the extremities (Wada *et al*., 2018:291). Araujo *et al*. (2015:28) also agreed on the latter and stated that dynamic core and lower extremity stability are grounded on the CNS and neuromuscular function of the core. Zazulak *et al*. (2007:1123) concluded that many athletic activities, including jumping, running and cutting, are inherently unstable in nature and are therefore dependent on accurate sensory input and adequate CNS responses throughout the kinetic chain in order to maintain stability.

The terms 'stabilisation', 'strengthening', and 'muscle activation' are frequently considered as independent training goals. Nonetheless, stabilisation is an outcome of multiple muscle forces originating from the CNS (Wirth *et al*., 2017:402). Activity of the core muscles, together with its ability to contract (muscle mass), generate these aforementioned forces which, consequently, result in a stable spine position. Muscle mass refers to the size of muscles that influences the amount of force that can be produced (Akagi *et al*., 2009:564).

The CNS is accountable for the activation of the core muscles in a task-specific way. Therefore, stabilisation is the effect of muscle activation through the CNS (Figure 2.1), whereas strengthening denotes enhancements of force creation (Wirth *et al.*, 2017:402). The amount of force needed for core stabilisation is subjected to the neuromuscular function and specific motor task. McGill (2010:39) states that only neuromuscular function, in order to activate muscles, is essential in core stability training. By comparison, small muscle mass with high activation generates a lesser amount of force than large muscle mass with high activation.

Occasionally, training outcomes are developed by means of force principles related to walking and standing (Lederman, 2010:87). Nevertheless, these force principles are not adequate for sport and activities of daily living. The neuromuscular function required in everyday life for activities such as carrying and lifting, surpasses the strains of walking, standing and some exercises for core stability training. To evaluate the forces which the core musculature must deal with, ground reaction force of the specific sport task should be taken into account (Lederman, 2010:87). Wirth *et al*. (2017:402) highlight that force generation, as a result of neuromuscular function, is a necessity for stabilisation of the spinal column.

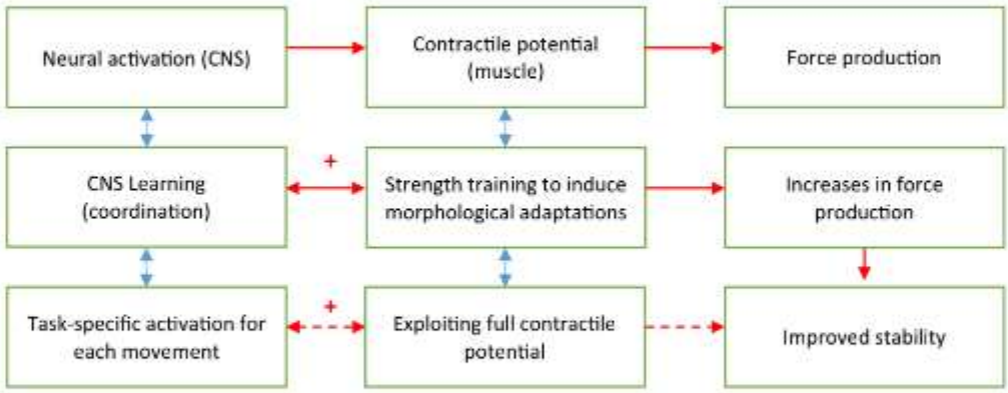

Figure 2.1: Schematic illustration of the relationship between stability and force generation (Wirth *et al*., 2017:402)

Previous studies have evaluated core muscle activation and the correlation with athletic performance, but in the sport sector, movement is needed to reach a ball, kick a ball and to run away from or around opponents, and core stability through activation of the functional and dynamic muscles in agreement with these stimuli is essential. Core stability performance is not only assessed by the strength and endurance abilities of the core muscles, but should include coordination, muscle recruitment through the CNS and optimal neuromuscular function of all the structures involved (Warren *et al.*, 2014:28).

2.2.4 The kinetic chain

The human body's kinetic chain refers to the integrated and coordinated movement of joints and extremities (Brukner & Khan, 2017). The upper kinetic chain includes the spinal column, shoulder blades, shoulders, upper arms, elbows, forearms, wrists and fingers. The lower kinetic chain consists of the spine, pelvis, hips, thighs, knees, lower legs, ankles, feet and toes (Sanchez, 2019). The individual segments within the kinetic chain must move in a specific pre-programmed order (Kibler *et al.*, 2006:191). This specific order of muscle activity in the upper and lower kinetic chain leads to a coordinated biomechanical activity. The kinetic chain is a result of this sequencing and, in upper extremity activities, the output and development of energy from a proximal to a distal direction (Sciascia & Cromwell, 2012:1). Dynamic activities of the upper extremity, such as serving, hitting and throwing, take place as the result of the coordinated, sequenced, multisegmented joint movements and muscle activities, which are identified as the body's kinetic chain. Optimal use of the kinetic chain enables that a maximum force is generated through the core and accurately transferred to perform these activities using the arm. The core provides the proximal musculoskeletal platform of stability for the activity of these sequential links within the lower extremity kinetic chain. The core is an integration of the passive, neural, and active subsystems (Hoffman & Gabel, 2013:692). The active subsystem comprises the local and global core stability muscles and the global mobility core muscles (Comerford & Mottram, 2001:16; Brukner & Khan, 2017). The latter serves as focus of this research as valid and reliable testing procedures have been described for muscle characteristics.

Adaptation or injury to any link within the kinetic chain may cause local dysfunction but may also involve the proximal and distal regions. Any suboptimal sequence in the kinetic chain can be considered as a substantial mechanism of overuse for a sports injury (Comerford & Mottram, 2001:15). The important role that core muscles have in the kinetic chain resulted in the hypothesis that poor activation of the core muscles may restrict an athlete's performance in sport tasks, particularly those executed in an upright position, as detected in running tasks. Furthermore, it has been hypothesised that improved specific core muscle function could lead to the improvement of related sports performance. Nonetheless, such a hypothesis has not yet been resolved in research up until now (Okada *et al.*, 2011:257), partially because of the different roles which specific core muscles have in different sport codes (Hibbs *et al.*, 2008:995). As a matter of fact, the role of core muscles has not yet been identified as a restricting aspect of performance ability in running sport codes.

2.2.5 The core and movement dysfunction

Muscle activation is pre-programmed for any athletic task. The CNS activation of the kinetic chain is reinforced by repetition (Kibler *et al.*, 2006:191). Within the classification systems of movement, the neural subsystems adjust the tightness in the active subsystems for the maintenance of effective stability (Hoffman & Gabel, 2013:695).

Movement of the lower extremities challenges proximal stability. In response, the CNS initiates the anticipatory feed-forward protective mechanism of the local stability muscles. The m. transverse abdominis, m. multifidus and pelvic floor muscles (m. pubococcygeus, m. puborectalis, m. iliococcygeus and m. coccygeus) are suggested to co-contract or biomechanically "tighten" in anticipation of lower extremity movement (Sapsford, 2004:4).

Biomechanical stiffness of the local stability muscles refers to active and/or passive tension resisting a displacing force. This muscular stiffness is reflex-mediated and regulated by muscle spindle afferent input. Inability of the stability muscles to resist fatigue may cause decreased facilitation from the primary spindles. The resulting decrease in proprioception along with the repetitive low load leads to a decrease in dominance of the tonic motor neurons (Comerford & Mottram, 2001:16). The high-threshold global mobilisers are in turn also reliant on this stability to produce torque. As such, dysfunction in the stability systems may lead to a decrease in athletic performance as the mobilising muscles become more responsive to low-threshold stimulus.

Of even more significance, core dysfunction can increase the risk of sustaining overuse injuries as it results in supra-physiological loads secondary to suboptimal lower extremity mechanics. This risk is intensified by the loss of anticipatory recruitment of the local active subsystem that may be persistent in the presence of pain and/or pathology (Comerford & Mottram, 2001:21). The adapted model of movement dysfunction (Figure 2.2) displays this intricate role of stability dysfunction in injury causation (Comerford & Mottram, 2001:23).

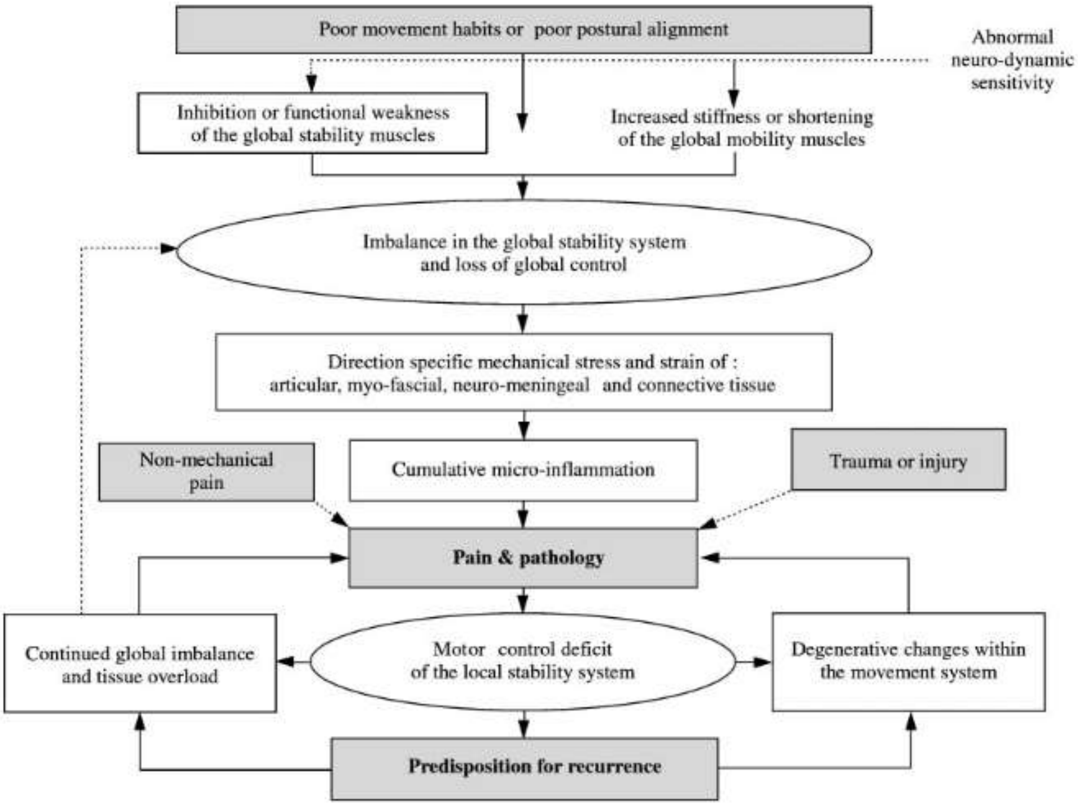

Figure 2.2: Movement dysfunction model (Comerford & Mottram, 2001:23)

This model shows that poor habits of movement lead to imbalance between global stabilisers and mobilisers. This then generates stress in a specific direction and strain on different structures that develop pathology if overloaded. Pathology then causes dysfunction of recruitment of local stabilisers. This contributes to a risk for recurrence, early development of degenerative changes and global imbalances.

2.3 TESTING OF FUNCTIONAL CORE STABILITY

Many studies have investigated core stability and used various tests to assess core stability. However, there is still a lack of valid and reliable test batteries to assess the core and, subsequently, in a functional manner. Allen *et al*. (2014:2064) reported that in a functional activity, it is challenging to isolate the core muscles in order to assess core stability, due to the stabilising role of the pelvis during movement. In order to isolate the core muscles, the pelvis should be stable, otherwise any movement will integrate the gluteal and hamstring muscles when performing a back-extension movement, for example. Consequently, specialised equipment has to be used to target the back extensors (m. erector spinae) which makes assessment of the core in isolation challenging.

Research conducted by Allen *et al*. (2014:2068), concluded that the most effective method to evaluate the overall function of the core is to use multiple assessment outcomes that target the m. multifidus, m. transverse abdominis and m. erector spinae. Furthermore, Araujo *et al*. (2015:33) found improvements in core muscle endurance outcomes but concluded that it is incorrect to assume that strength adaptation in core muscles was also found due to the difficulty of assessing maximal isometric strength of the core muscles. Chaudhari *et al*. (2014:2739) also agreed that only one assessment of the core, in order to determine the overall function, is not enough. Chaudhari *et al*. (2014:2739) used the single-leg raise test to determine core motor control in baseball athletes and concluded that it does not mimic the core motor control required during a pitching motion and, furthermore, does not assess muscle strength and the influence of surrounding muscles controlling the foot, ankle and knee. For this reason, a more functional, strenuous and sport-specific test could better assess core stability in the pitching motion.

A prone plank is a well-known test used for the assessment of core stability. However, Atkins *et al*. (2015:1614), reported that in swimming, even though the prone plank is executed in a "swim-like" orientation, it fails to mimic water-based movements and activities and should not be used as the only assessment for core stability. Another consideration to evaluate the impact core stability has on athletic performance is to assess it regularly in order to link a value to core stability immediately before an event/match/tournament (Chaudhari *et al*., 2014:2739). However, in an ideal world, this will not be realistic due to the time constraints of tournaments or matches played daily.

The DLLT with a pressure biofeedback unit is another modality used to determine core stability and has been found to be an appropriate test because it assesses the NMC of the abdominals, which is required for most sport activities (Sharrock *et al*., 2011:70). This test determines the pressure changes as the stabilisation system tries to stabilise the trunk whilst lowering the legs. The DLLT, with an ICC = 0.98, requires a great level of core activation to assist the trunk when lowering the legs because of the small base of support and long lever arm (Sharrock *et al.*, 2011:67). No significant correlation was reported between the DLLT and various athletic performance tests, such as the T-test (r=0.05), 40 m sprint (r=0.14) and the vertical jump (r=0.17). Loubser (2018:107) also used the DLLT to assess core stability and found large correlations with the vertical jump test and medicine ball chest throw test in female Kovsie first team athletes overall for hockey, basketball and soccer.

It can be summarised from all the above-mentioned core stability tests that no single gold-standard assessment is defined or proposed for functional core stability (Brukner & Khan, 2017) and that a significant correlation between core stability tests and athletic performance has not yet been proven. The role of functional core stability in peak athletic performance in different sports needs to be further researched (Loubser, 2018:5). The latter further emphasises the need for research to provide evidence with regard to the specific functions of the core, including strength, endurance and motor control, individually, to determine the importance of each function (Loubser, 2018:108). Therefore, this research study selected seven tests that incorporate all of these functions with the aim to assess core stability and to fill the gaps in available literature to help find valid and reliable tests to conclude whether a possible relationship exists between core stability and athletic performance.

2.4 ANTHROPOMETRIC CHARACTERISTICS OF ATHLETES

Elite athletes are expected to have good speed, agility, explosive power and sport-specific skills. Durandt *et al*. (2006:38) considered anthropometry as an important component for optimal athletic performance in elite athletes. Depending on their sport and position played, the anthropometric profile of each athlete may vary within a team. An anthropometric profile comprises height, body weight, body fat percentage (BF%), and body mass index (BMI). It is also important to differentiate between the anthropometric profiles of males and females (Arabi *et al*., 2004:1428). Body weight is greater in males than in females, whereas body fat percentage is greater in females (Arabi *et al*., 2004:1428).

2.4.1 Height and body weight

Height and body weight are considered as important variables that influence athletic performance. Height and body weight are measured using valid and reliable equipment, such as a stadiometer (height) and an electronic scale (body weight) (Marfell-Jones *et al.,* 2006:5). It is hypothesised that elite athletes should be tall and have low body weight in order to perform optimally in their respective sport codes. On the contrary, Arazi *et al*. (2015:36) established that the best endurance athletes are short and have low body weight. Sharma and Kailashiya (2017:2) found that male hockey players are taller and leaner than female hockey players, which could contribute to the fact that male athletes are stronger than female athletes due to more muscle mass than fat mass. Research carried out by Naicker *et al*. (2016:120), determined the anthropometric profiles of 30 South African female field hockey players and reported an average height of 1.64 ± 0.52 m and an average body weight of 62.6 ± 8.45 kilograms (kg). Ferreira and Spamer (2010:61) assessed the anthropometric profile of 25 North-West University female netball players and found an average height of 1.75 ± 0.03 m and an average body weight of 68.2 ± 1.02 kg. These results indicate that the mean height and body weight of elite female netball players are much higher when compared to national female hockey players. On the other hand, Sedano *et al*. (2009:390) reported lower mean values for height (1.61 ± 0.05 m) and body weight (57.7 ± 7.5 kg) in elite female soccer players in comparison with netball and hockey. Furthermore, Attlee *et al*. (2017:148) determined the anthropometric profile of United Arab Emirates national female tennis players, aged between 15 and 24 years, and found an average height of 1.58 ± 0.03 m and an average body weight of 52.6 ± 3.2 kg. These results are much lower when compared to the other sport codes and could possibly be due to the sizable age range. It can be concluded that height and body weight of female athletes vary within sports depending on the respective sport code.

2.4.2 Body fat percentage and BMI

Different sport codes have varying skill levels, including suitable BF% and BMI as part of the anthropometric characteristics of players (Attlee *et al*., 2017:143). BF% values of 6-13% and 14-20% are desirable for male and female athletes, respectively (Muth, 2009), and a BMI of 18.5-24.9 kilograms per metres squared (kg.m^{-2}) is considered acceptable in elite athletes (Dumke, 2017:70). BF% is measured with a skinfold calliper and calculated according to the Carter equation, and bone breadths are measured by a bone breadth calliper. Both BF% and bone breadths are determined as described by Marfell-Jones *et al.* (2006:5). BMI is calculated by dividing body weight in kilograms with height in metres squared.

As mentioned previously, endurance athletes display low body weight (Arazi *et al*., 2015:36). Consequently, these athletes also have very low BF% (less than 7%). BF% and BMI of United

Arab Emirates national female tennis players have been found to be 40.9 ± 6.9% and 27.5 ± 0.8 kg.m^{-2}, respectively (Attlee *et al.*, 2017:143). These values are much higher than the desired norms for BF% (14-20%) and BMI (18.5-24.9 kg.m^{-2}). This could be attributed to an insufficient diet and/or improper training or conditioning of these athletes. Ferreira and Spamer (2010:64) reported an average BF% of 26.6 ± 0.43% and a mean BMI of 22.4 ± 0.6 kg.m^{-2} in elite North-West University female netball players and, subsequently, concluded that an above-average BF% and BMI in elite netball players may have a negative influence on athletic performance, as well as contribute to musculoskeletal injuries. In a study conducted by Naicker *et al*. (2016:120), 30 South African female field hockey players were assessed and reported a mean BMI of 23.3 kg.m^{-2}. Furthermore, Sedano *et al*. (2009:390) reported lower mean values for BF% (20.1 ± 5.5%) and BMI (22.3 kg.m^{-2}) in elite female soccer players in comparison with tennis, netball and hockey. When BF% and BMI are considered in general, Sharma and Kailashiya (2017:4) reported that higher BMI with lower BF% values are possible in athletes and, furthermore, stated that BMI should be cautiously used as an indicative measure of ideal weight among elite athletes.

Research carried out by Arazi *et al*. (2015:35), determined the anthropometric profile of national cross-country runners and found the runners to fall in the mesomorphic and ectomorphic categories of somatotyping. Sharma and Kailashiya (2017:1) investigated the correlation between anthropometric characteristics and strength and flexibility in young Indian field hockey players. It was concluded that the anthropometric characteristics of hockey players have a noteworthy relationship between strength and flexibility and are important to enhance athletic performance (Sharma and Kailashiya, 2017:1). Ferreira and Spamer (2010:56) determined the athletic profile of elite athletes participating in netball for North-West University, between the ages of 18 and 25 years, concerning the anthropometric profile and athletic performance (balance, agility and explosive power). The results reported that shortcomings in one of these assessments (anthropometry and athletic performance) could influence netball players' performance (Ferreira & Spamer, 2010:64). Research conducted by Sedano *et al*. (2009:387) compared the anthropometric profiles of female soccer players by playing position and competition level and found that elite soccer players had better athletic performance (kicking speed) than the non-elite players and consequently better anthropometric profiles. On the other hand, Attlee *et al*. (2017:142) reported different results than the previously-mentioned studies. This study, conducted by Attlee *et al*. (2017:148), assessed the body composition and endurance performance (step test) of female tennis players and found that the body composition of players was significantly different, even though the endurance performance of players showed no statistically significant difference. The latter results are proof that BF% and BMI should not be the main indicators of athletic performance in elite athletes. Conclusively, the anthropometric characteristics of athletes are only one of many contributing factors to athletic performance and should be considered interchangeably with other factors, such as flexibility, balance, strength, explosive power and previous injuries.

2.5 COMPONENTS OF THE CORE

2.5.1 Core strength

Akuthota and Nadler (2004:86), define core strength as the involvement of the anatomy around the lumbar spine in the maintenance of functional stability. This definition differs from the usual notion of strength in athletes which has been proposed by Lehman (2006:28) as a maximum force produced by a muscle group at a certain velocity. The training of core strength includes few repetitions performed at a high load with tension in the core muscles (Saeterbakken *et al.*, 2011:717). Core strength is vital for sport performance and should be considered as an important component to determine core stability (Sharrock *et al*., 2011:66).

The existing literature on core strength testing specifically, and not considered as part of core stability, are limited. Saeterbakken *et al*. (2015:56) assessed core strength using the Bering-Sorensen tests, which included an isometric back extension test, lateral flexion test and abdominal flexion test using maximal effort over three seconds.

Resistance exercises of the core are important to improve strength, balance and flexibility in general (Wahl & Behm, 2008:1360). Depending on the sport and position played by athletes, good core strength is essential to improve athletic performance. There is limited literature observing the outcome of core strength on athletic performance in female athletes (Brown, 2011:39). Even though some research has concluded that there is a beneficial influence with regard to athletic performance as a result of enhancements in core strength, these statements have mostly been assumed to be grounded in traditional assessments (Faries &

Greenwood, 2007:10). Hibbs *et al.* (2008:997) stated that core strength and a sense of stability are important for optimal athletic performance in nearly all sport codes and actions. The reason for the latter is because of its three-directional characteristics during most actions in sport, which stress that adequate hip and trunk muscle strength deliver sufficient core strength. Certain sports entail good balance, and some, the generation of force and body symmetry, nevertheless, good core strength throughout all three movement directions is required in all sports (Hibbs *et al.*, 2008:1002).

Fernandez-Fernandez *et al*. (2013:232) assessed the outcomes of core strength training on the velocity of a serve in nationally ranked junior tennis players and found an improvement in performance. However, Reed *et al*. (2012:698) suggested that core strength training only is not enough to improve athletic performance. Sato and Mokha (2009:133) used ground reaction forces to investigate the effect of core strength training on running performance and reported faster running times but no improvements in ground reaction forces. These results can be due to the fact that core strength training only is not sufficient to improve athletic performance. Consequently, coaches should use integrated sport-specific training in their programmes to include all components involved in a respective sport code.

2.5.2 Core endurance

Core endurance can be defined as "the potential of the core muscles to resist fatigue during continuous low load activities" (Comerford & Mottram, 2001:16). Core endurance, and not only strength, plays an important role in a strong core. The endurance trunk stability test, prone extension test and the side flexion test are all measurements to determine core endurance (Akuthota *et al*., 2008:41; Nesser & Lee, 2009:23). Existing literature has reported significant correlations with core endurance and the medicine ball chest throw and T-test, although it is not considered to improve athletic performance overall (Allah & Nagi, 2013:5).

Good core endurance enables the spine to control movement over a time period to prevent fatigue when performing athletic activities (Bliss & Teeple, 2005:179). Muscle fatigue increases the perception of effort to activate the slow motor units due to reflex inhibition of the motor neuron pool. Global muscle efficiency also decreases with fatigue due to length associated changes in directional flexibility and stiffness (Comerford & Mottram, 2001:18).

Koblbauer *et al*. (2014:419) investigated the trunk movement changes experienced when an athlete becomes fatigued due to running, and if it correlates with core endurance. It was concluded that fatigue induced by running affected the movement of the trunk (increased inclination) and consequently relates to a lack in core endurance (Koblbauer *et al*., 2014:419). Similarly, Tong *et al*. (2014:244), reported limited running endurance induced by core muscle fatigue. Therefore, the ability of the integrated local and global active systems to withstand fatigue is crucial. Muscle endurance, rather than strength, is needed to ensure sufficient load transfer between the spine and the upper and lower extremities.

Clark *et al*. (2017:2289) researched the result of a 6-week core endurance training programme on the race times of high school cross-country runners. Thirty-five (35) participants were arbitrarily assigned to a core training group or a non-training group. The core endurance group performed a 6-week core endurance training programme together with their normal training. Both groups were tested before and after the intervention by executing four isometric endurance tests for hip extensors (m. gluteus maximus), hip abductors (m. gluteus medius), hip adductors (m. adductor longus, m. adductor brevis and m. adductor magnus) and core muscles (TrA, RA, m. erector spinae and the lumbar multifidus muscles). It was concluded that both groups had an increase in core endurance and improved race times. Consequently, core endurance training in addition to normal team training led by a coach may help to improve race times.

An 8-week training protocol, focussing on core endurance, was evaluated by Tse *et al.* (2005:547). They investigated the outcome of core endurance improvements on different assessments of athletic performance (40 m sprint, shuttle run, vertical and broad jump, overhead medicine ball throw and ergometer test). The researchers described an enhancement in the side bridge endurance test, but they failed to find a difference in any of the performance assessments. Nonetheless, this may be assigned to the fact that no components of NMC were trained, only core muscle endurance.

2.5.3 Core motor control

Core motor control can be defined as the activation of core muscles in a specific task as controlled by the CNS (Comerford & Mottram, 2001:23). Good motor control of muscles in the body increases a sense of effort occurring on a CNS level. Both the local and global systems then display with altered low thresholds and are responsible for the activation of a feed-forward mechanism of movement required in all types of sport (Comerford & Mottram, 2001:23). As previously mentioned, abdominal hollowing and abdominal bracing are exercises that can be used for this activation (Akuthota *et al*., 2008:41).

Various core motor control tests have been researched before. Noehren *et al*. (2014:1306) used the trunk stability test to determine core motor control. In addition to the aforementioned tests, the elbow-toe test (Okubo *et al*., 2010:748), single-leg raise test, as well as the Closed Kinetic Chain Upper Extremity Stability test (CKCUEST) have also been used in previous literature (Pontillo *et al*., 2014:497). The Star Excursion Balance test (SEBT) together with the Y-balance test are both reported as sufficient tests to determine core motor control (Gorman *et al*., 2012:3047; De La Motte *et al.*, 2015:358). The DLLT is another frequently used modality to determine the motor control of the abdominal muscles (Sharrock *et al*., 2011:67).

Hart *et al.* (2009:458) evaluated the correlation of core muscle fatigue with quadriceps activation to determine if changes occur in hip and knee kinematics during running and suggested that motor control of a neutral spine position is important in jogging kinetics to prevent the core from fatiguing.

Chaudhari *et al*. (2014:2734) assessed the relationship between core motor control and injuries in baseball players. Core motor control was evaluated with a single-leg raise test (Figure 2.3) in 347 baseball players playing on a professional level. Days missed due to injury over the season were recorded for each player. This study found that players with a lack in core motor control, when performing the single-leg raise test (greatest amount of anterior-posterior core movement), had a greater chance of missing a minimum of 30 days when compared to the players that illustrated good core control (least amount of core movement).

Figure 2.3: Example of the single-leg raise test (Chaudhari *et al.*, 2014:2735)

Based on the theory of the kinetic chain (Chappell & Limpisvasti, 2008:1081), poor NMC in any section of the kinetic chain could reorganise biomechanics and forces in upper extremity activities; hence, these two studies, which also evaluated balance in a standing position, are included. Radwan *et al.* (2014:8) evaluated shoulder pathology obtained during a non-contact mechanism in 61 athletes participating in overhead sports. Core motor control tests involved the Sorensen modified extensor endurance test, DLLT, single-leg balance test and the side bridge (Figure 2.4). Only the single-leg balance test standing time, which evaluated static balance, recorded decreased times in the shoulder pathology group. Furthermore, Garrison *et al.* (2013:752) also found a significant decrease in dynamic balance, as assessed by the Y-balance test (Figure 2.5) in collegiate and high school athletes, participating in baseball, with an elbow injury. Even though these studies have not reported decreased static balance control due to upper extremity injury or pain, they do speculate a possible association between poor core motor control, as assessed by the single-leg balance and Y-balance tests, and shoulder or elbow injury.

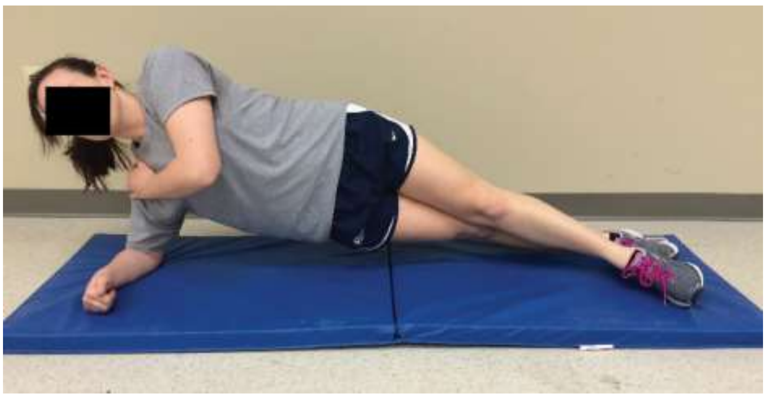

Figure 2.4: The side bridge endurance test position (Garrison *et al.*, 2013:753)

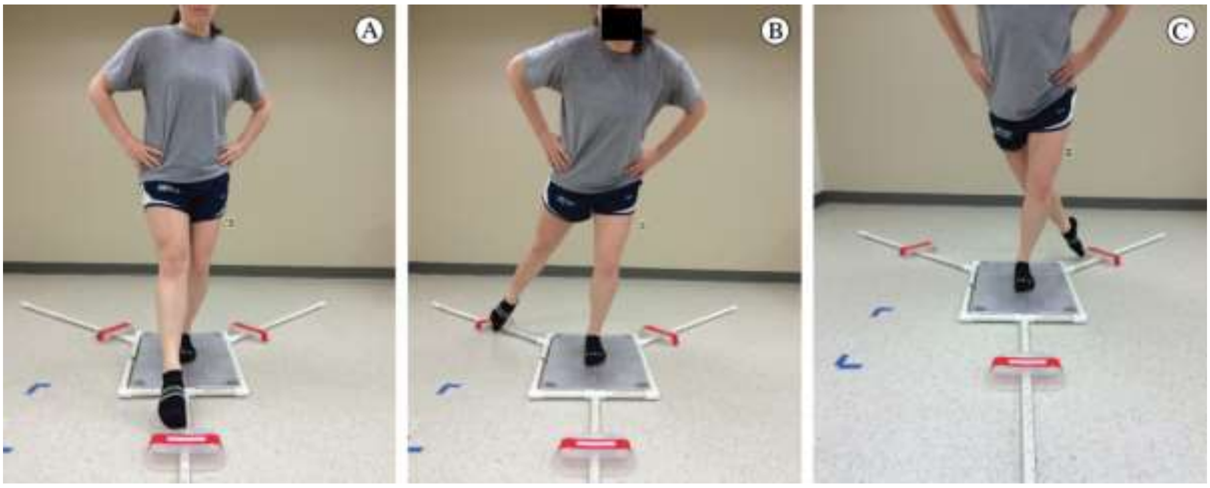

Figure 2.5: The Y-balance test performed in three directions (Garrison *et al*., 2013:754)

It can be concluded that the assessment and training of core stability has to be considered as an integration between core strength, core endurance and core motor control components. Therefore, common core exercises (sit-ups), core stability exercises (isometric plank), device or stability ball exercises (stability ball), functional free weight lower extremity exercises (squat and deadlift), and functional free weight upper extremity exercises (bench press and prone row) should all be included in a core stability training programme (Martuscello *et al*., 2013:1684).

2.6 COMPONENTS OF ATHLETIC PERFORMANCE

Athletic performance can be defined as the skills to perform athletic movements in game-like situations (Greene *et al*., 2019:1139). There are many physiological and structural factors of core stability that play a role in the performance of male and female athletes, but few researchers have evaluated them within a specific sport and even fewer have observed the differences between males and females (Ozmen, 2016:110; Greene *et al.*, 2019:1139). However, the New Zealand netball team has set national standards on various sport-specific athletic performance measures as a test battery for team selection (Netball New Zealand, 2020). The test battery includes anthropometric characteristics, explosive power (broad jump and vertical jump), speed (5 m, 10 m and 40 m sprint), agility (5-0-5 agility test) and aerobic fitness (Yo-Yo).

Several researchers showed that core stability differs between genders and influences the effectiveness of energy transfer in the body (Gordon *et al*., 2013:97; Ambegaonkar *et al*., 2014:604; Greene *et al*., 2019:1139). Males have greater levels of testosterone, resulting in the larger muscles and thus increases the ability to generate greater explosive power in comparison with females (Gordon *et al*., 2013:97). Moreover, females have a broader pelvis, which changes the angle of attachment of core muscles (Gordon *et al*., 2013:97), in this manner leading to a possibly weaker core (Greene *et al*., 2019:1139). It can be assumed that all of these differences between males and females could relate to variations in athletic performance.

Greene *et al*. (2019:1138) investigated the effect which core stability has on performance variables, such as dynamic stability, agility and explosive power generation of lacrosse players participating on collegiate level, and the transparency of different performance measures in females. Twenty (20) female lacrosse players, executed the pro-agility shuttle (PAS), SEBT, prone plank, bilateral side planks and the countermovement jump (CMJ) on two testing sessions. The PAS correlated with the prone plank (r=-0.50), however, the study failed to find any relation of core stability with the performance measures. The differences in PAS as well as the CMJ were found to be statistically significant, but not the dynamic stability performance or core stability. All three performance measures of agility, dynamic stability and explosive power generation were not associated with core stability in female lacrosse players. A significant difference was also reported in dynamic stability in the SEBT left and right leg combined results. It was concluded that core stability has no direct relation to athletic performance in female lacrosse athletes.

Research carried out by Reed *et al.* (2012:697) also investigated whether a relationship exists between core stability and athletic performance. The inclusion criteria were aimed towards core training (individual or combined into a rehabilitation programme), assessment of sports performance, and participants younger than 65 years of age. The investigation produced 10 randomised control trials and 14 non-randomised trials.

The above-mentioned research studies mostly determined the outcome of core strength on lower extremity performance. Most of these studies reported mixed results with three of the ten studies demonstrating better running performance after a core training programme and two demonstrating no change. Nonetheless, those studies reporting change used adults that are physically active and not conditioned athletes. Six of the research studies that assessed components of upper extremity performance, report that endurance of the core is not a good indicator of sports ability or performance. Yet, a more recent randomised control trial evaluating the outcomes of core strength training on tennis performance in national junior players, reported improvement in the velocity of a serve following a 6-week intervention programme (Fernandez-Fernandez *et al*., 2013:232). Reed *et al*. (2012:698), recommend that core training alone must not be the main focus for training programmes with the aim of improving sports performance. It is rather suggested that training should be directed to the athlete's specific sport code, as research using these training techniques illustrated enhanced performance in bat speed and golf club swing speed, which are sport-specific tasks.

Reed *et al.* (2012:697) only used studies that included an intervention of core training. Numerous non-intervention research studies that evaluated the relationship between core stability and athletic performance have been conducted. Nesser *et al.* (2008:1750) assessed the relationship between core stability and athletic performance by testing Division I football players using three power lifting exercises to assess strength. Core endurance and athletic performance (speed, CMJ and a shuttle run) were also assessed. Core strength as a whole was assessed by the total isometric hold times of the trunk flexion, trunk extension, and left and right side bridge tests. The researchers hypothesised that improvements in core strength may relate with improved strength and athletic performance tests. Significant relationships were reported between core strength and speed, agility exercises, 1RM squat and 1RM bench press. Okada *et al*. (2011:252) also differentiated between core stability, Functional Movement Screening (FMS) and athletic performance in athletes. Core stability was assessed using four endurance tests, namely interrupted core flexion and extension and right and left side bridge. This was the first study conducted involving, among other athletic performance assessments, an upper extremity athletic performance test using a reverse overhead medicine ball throw. The researchers found weak to moderately significant correlations between core stability assessments and athletic performance. There were no significant correlations between core stability and FMS. It should be considered that, in both studies (Nesser *et al*., 2008:1750; Okada *et al*., 2011:252), the researchers only assessed core muscle endurance, and not core NMC, and the terms "stability" and "strength" were interchangeably used.

Loubser (2018:4) used the DLLT to determine core stability and associated this with four athletic performance tests, namely 40 m sprint, T-test, vertical jump and medicine ball chest throw. The participants (52 females) were selected from first team university athletes participating in hockey, basketball and soccer. The vertical jump and medicine ball chest throw were the only performance tests that significantly correlated with the DLLT in female basketball players. Overall (all sports), small ($r<0.3$) correlations were reported between core stability and the athletic performance tests.

Conclusively, core stability training is physiologically thought to lead to a larger maximal explosive power and also to a more effective use of the shoulder/arm and leg muscles. This hypothetically leads to a lower risk of injury and encouraging outcomes on athletic performance in terms of agility, speed, and explosive power (Hibbs *et al.,* 2008:1002). Agility, speed and explosive power are succeeding aspects of physical capability and desirable athletic performance, and play an important role in most sports (Nikseresht *et al.*, 2014:384). For this reason, clarity should be reached about the effect of core stability on athletic performance, especially that of females.

2.6.1 Agility

Bal *et al.* (2011:272) specified agility as a direction changing skill to uphold or control body position in various sport actions. Agility and fast reflexes are often inherent characteristics. Several training exercises help to enhance agility by manipulating the adaptation of the neuromuscular system, Golgi-tendon organs, muscle spindles, tendons, joints and proprioception and body position control. Agility consists of forward running, backward running and side running movements that entail a great deal of coordination. Haugen *et al.* (2016:2) stated that a lack in core stability can alter biomechanics, leading to injury. Training exercises which include change of direction, stopping and starting, and have an explosive component can help athletes to reduce the risk of injuries, improve agility and, consequently, athletic performance (Nikseresht *et al.,* 2014:383).

Spiteri *et al.* (2014:2416), reported greater lower extremity strength and vertical explosive power in males. This could have led to an increased time in the PAS as it could have enabled males to change directions faster and to run faster in relation to females. Ferber *et al.* (2010:52), also reported that females displayed differences in gait patterns and hip and knee kinematics in comparison with males. Consequently, the latter could also have led to the significant difference in agility between genders. In addition to the aforementioned research, Sood (2013:4) suggested that body BMI, sport-specific training, explosive power and reaction time are all necessary components to improve agility performance in female tennis players. Therefore, coaches and trainers should include all these variables in order to improve agility performance in elite athletes.

In a study conducted by Loubser (2018:81), both negative and positive correlations were reported between core stability (DLLT) and the agility T-Test in female Kovsie high-performance athletes. Soccer (r=-0.14) and basketball (r=-0.45) had negative correlations between core stability and agility and hockey (r=0.20) had a positive correlation (Loubser 2018:81-83). These correlations can possibly be due to the fact that hockey is a sport code that requires less agility than soccer and basketball, respectively. It can also be concluded that the training programmes of hockey did not include the agility modality as part of their conditioning.

Afyon *et al.* (2017:239) assessed the outcomes of an 8-week core stability training programme on the agility skills of soccer players. Twenty (20) participants were in the experimental group (EG) (age = 23.17 ± 1.86 years, height = 174.7 ± 5.04 cm, body weight = 72.11 ± 3.75 kg) and 20 participants in the control group (CG) (age = 22.03 ± 0.50 years, height = 176.7 ± 7.04 cm, body weight = 73.11 ± 6.12 kg). In this study, the agility was assessed by the T-Drill Agility Test and the Illinois Agility Test. Both groups' agility was tested twice per week for the duration of 8 weeks, before and after training, whilst continuing with the usual training 4 days per week. In addition, the EG executed a 30-minute core training programme, two days per week. No significant differences were found between the pre-test values of both groups , but the agility post-test values of the CG showed better results in comparison with the pre-test values. The EG showed improvements in both agility assessments when observing the pre- and post-test values. Based on these findings, additional core stability training can assist in the improvement of agility skills in soccer players. In contrast, research conducted by Sever and Zorba (2018:29) and Prieske *et al*. (2016:55), found no improvement in agility performance after an intervention of core training in football players.

Venter *et al*. (2017:189) used FMS to evaluate the relationship with agility performance (5-0-5 agility test) in 19 elite university female netball players. The latter concluded that netball has specific demands and when evaluating performance, trainers and coaches should use various tools for a comprehensive performance evaluation. Optimal athletic performance in netball is generated from a complicated interaction of various factors (flexibility, strength, endurance, explosive power, speed and agility), of which physical conditioning and technique are the most important (Venter *et al*., 2005:3).

It was found that the netball players with a higher total score of the FMS ran better times on the 5-0-5 agility test (p=0.02). Barber *et al*. (2015:379) reported that the 5-0-5 agility test has been shown to have a high test-retest reliability when assessing change of direction amongst female netball players (ICC = 0.96-0.97).

This current study used the agility T-test to determine the agility of the athletes with a reported ICC = 0.82-0.96 (Munro & Herrington, 2011:1470). Wood (2008a) categorised the times to complete the agility T-Test for female athletes as excellent (<10.5 s) and good (10.5-11.5 s).

2.6.2 Speed

Speed can be defined as the quickness of an individual over a distance. Speed is of great significance in most sports which involve direction change, acceleration and deceleration, and leaping movements. Various factors, including age, gender, anthropometric profile, range of motion, flexibility, muscle length and muscle strength could have an influence on speed (Nikseresht *et al.*, 2014:383). Voluntary muscle contraction permits the body to execute specific actions. A stronger athlete contains the ability of stronger muscle contractions, leading to an enhanced sprinting performance (Suchomel *et al*., 2016:1426).

Loubser (2018:81) determined the relationship between core stability (DLLT) and speed (40 m sprint) in female Kovsie high-performance athletes. Both negative and positive correlations in different sports were reported. Soccer (r=-0.23) and basketball (r=-0.47) had negative correlations between core stability and speed, and hockey (r=0.13) had positive correlations (Loubser, 2018:81-83).

Taskin (2016:115) determined the influence of a 6-week core stability training programme in female soccer players. Forty (40) participants were evaluated and divided into a core stability training group (n = 20, mean age = 19.05 ± 1.15 years, height = 160.6 ± 4.22 cm and weight =

56.45 ± 3.33 kg) and a CG (n = 20, mean age = 18.55 ± 0.76 years, height = 159.1 ± 3.86 cm and weight = 52.2 ± 3.60 kg). The participants in the CG only took part in the pre- and post-test assessments. The core stability training group performed an additional 12 core exercises as part of their usual training. Speed and acceleration were assessed by the 10 m and 30 m sprint test. The core stability training group demonstrated improved speed and acceleration performance after the 6-week intervention. Consequently, Taskin (2016:115) concluded that core stability training is important for optimal athletic performance.

This current study used the 40 m sprint to determine the speed of the athlete and have a test reliability of ICC = 0.89-0.97 (Triplett, 2017). Kolsky *et al*. (2010:62) found mean values of 6.65 s ± 0.52 s for moderately trained females for the 40 m sprint.

2.6.3 Explosive power

Explosive power is well-defined as the amount of force a person can exert in a certain amount of time (Fd/t) (Bal *et al.*, 2011:272). Explosive power is an essential factor for professional athletes, enabling them to reach their peak performance. The better the skill of athletes to perform physically demanding tasks, the faster their ability to generate the movement, and as a result, enhancing their performance during activities such as swimming, kicking as well as running (Macedonio & Dunford, 2009:11). Furthermore, maximal muscle strength gained from the major muscle groups of the upper and lower extremities for explosive power needs integrated core stability training (Nikseresht *et al.*, 2014:383). Clarke (2009:5) determined the relationship between core stability (as part of NMC), core endurance and athletic performance in field hockey players and found that both components of core have an influence on upper body explosive power performance (pushing and hitting techniques). Filipcic and Filipcic (2005:164) reported that core muscle strength made a statistically significant difference in the speed and explosiveness of arm movements in female tennis players.

According to Greene *et al*. (2019:1146), males generate more explosive power in the CMJ due to a higher rate of force development (RFD) when reaching the eccentric jumping phase. McMahon *et al*. (2017:5) demonstrated that males have increased leg stiffness when performing the CMJ. By using the latter technique, males could have displayed decreased movement times, leading to a higher explosive power generation. A larger quantity of muscle mass could have also enabled males to make better use of the contractile characteristics of muscles, maximal force capacity, and RFD compared to females (Carvalho *et al*., 2012:2447).

Loubser (2018:81) researched the relationship between core stability (DLLT) and upper and lower extremity explosive power using the medicine ball chest throw and vertical jump tests in female Kovsie high-performance athletes. Hockey and soccer were found to have no statistically significant difference between core stability and both the explosive power performance tests. The exception was basketball which reported a statistically significant difference for both the medicine ball chest throw and vertical jump tests, as well as hockey for the vertical jump test (Loubser, 2018:81-83).

A study conducted by Dinc and Ergin (2019:550) assessed the effects of an 8-week core stability intervention on explosive power performance. Twenty-eight (28) runners (participating in middle- and long-distance events) were divided into an EG (n=15, age = 19.5 ± 1.2 years, body weight = 64 ± 8.9 kg) and a CG (n=13, age = 19.4 ± 1.5 years, body weight = 67.4 ± 10.3 kg). The EG performed 13 core stability exercises three days of the week, in addition to the normal training sessions. Pre- and post-tests of the standing long jump were used to assess the explosive power. After the 8-week core stability intervention, both groups demonstrated a significant increase in the explosive power performance. Similarly, Taskin (2016:115) evaluated the effect of a 6-week core stability intervention on vertical jump and long jump performances of female football players and found an improvement in the distances of both explosive power tests.

Saeterbakken *et al*. (2011:712) investigated the effect of core stability training on upper extremity explosive power by assessing the throwing speed performance of female high school handball players. Twenty-four (24) participants (mean age = 16.6 years) were allocated to two groups: a sling exercise training group and a CG. All participants continued with usual training for 6 weeks. The sling exercise training group executed a progressive core stability programme, including six unstable, closed kinetic chain exercises two days per week. The maximal throwing speed of players was assessed before as well as after the 6-week core stability intervention. This study found that maximal throwing speed improved significantly with 4.9% in the sling exercise training group after the core stability intervention but was unchanged in the CG. Saeterbakken *et al*. (2011:712) concluded that “a stronger and more stable core may contribute to higher rotational velocity in multi-segmental movements”, leading to improvements in upper body explosive power. Zingaro (2018:18) has reported similar results and found that the force generation during a serve in tennis originates from the core and upper extremity muscles. Therefore, it can be concluded that the upper extremity explosive power in a tennis serve is mainly from the core.

The current study used the vertical jump as a measure of lower extremity explosive power due to the fact that explosive power is seen as a primary factor in most sports (Suchomel *et al*., 2016:1420). The vertical jump has an ICC = 0.97-0.99 (Rodríguez-Rosell *et al*., 2017:196) and is considered as a great instrument to determine lower body performance. Furthermore, Haff and Triplett (2016:445) reported vertical jump heights of 47 cm for competitive female university athletes.

On the other hand, the medicine ball chest throw was used to determine upper extremity explosive power with an ICC = 0.87-0.95 (Sayers & Bishop, 2017:311). As reported by Sell *et al*. (2015:156), medicine ball chest throw values are 2.8 m ± 0.49 m for competitive female athletes.

2.7 FUNCTIONAL TRAINING OF THE CORE

To date, literature has been unsuccessful regarding the right methods of functional training of core (Hibbs *et al*., 2008:999). Factors such as muscle reaction time, neural function, injuries and static and dynamic nature of the core all play a role in order to design a functional core training protocol, including a combination of strength, endurance and NMC exercises (Hübscher & Refshauge, 2013:939). Allen *et al*. (2014:264) also agreed on the aforementioned and stated that training the core in a functional manner, using various exercise modalities, is more effective than training only one group of muscles. This can be due to the fact that the core muscles cover a large surface area that needs to be taken into consideration during training. An organised training programme that starts with NMC of the local stabilisers, followed by stabilisation exercises to endorse simultaneous activation of local and global stabilisers, and then progressing to dynamic exercises that encounter core stability may be effective (Figure 2.6) (Akuthota *et al.*, 2008:42). Core stability assessments can direct where, as indicated in Figure 2.6 below, the athletes have to start their training programme.

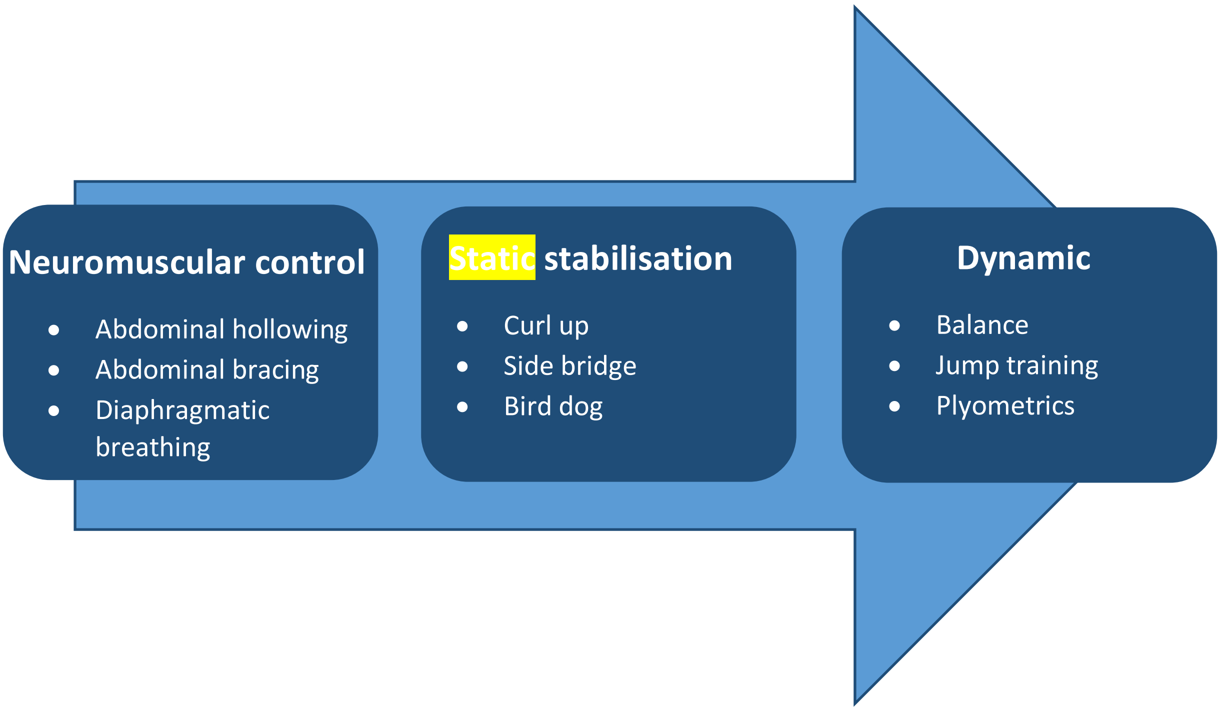

Figure 2.6: Schematic representation of an integrated core stability training programme (Bliven & Anderson, 2013:516)

Training programmes trying to improve weak areas in an athlete's core stability contain approaches that redeem control of the location and dimension of the deficit at a suitable point in training. Naturally, programmes are created to:

- increase range of motion of joints and muscle flexibility;
- enhance stability of joints;
- improve performance of muscles;
- optimise function of movement (Hibbs *et al.*, 2008:1002).

A study conducted by Endo and Sakamoto (2014:689) investigated the association between core muscle endurance training and injuries. Junior high school baseball players participated in this study. Upper extremity and trunk/back non-contact injuries were responsible for 60% and 14% of all injuries sustained during the season, respectively. Conversely, no association was found between core muscle endurance (side bridge and prone bridge) and elbow or shoulder injuries in these players.

Pontillo *et al*. (2014:497) testified on a potential risk for injury of American football players. The data in this study demonstrated that shoulder injuries during the season may possibly be recognised through their performance during the pre-season on the CKCUEST. The latter is executed in a prone plank position where the player should alternate the upper extremities by touching one of two lines positioned 91.4 centimetres (cm) apart for a duration of 15 seconds (s) (Figure 2.7). Based on the results, the researchers concluded that a performance of less than 21 touches may indicate players as an injury risk in the future. Altogether, the above-mentioned studies propose that poor core stability (as assessed by the single-leg raise test and CKCUEST) could be a possible risk factor for upper extremity injury in the future (Pontillo *et al.*, 2014:497).

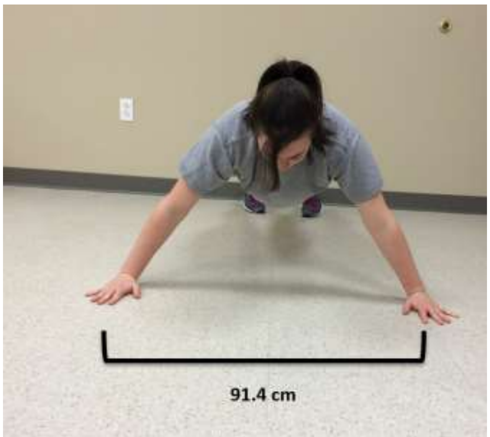

Figure 2.7: Start position for the performance on the CKCUEST (Pontillo *et al*., 2014:501)

Two cohort and case control studies of swimmers also support the hypothesised relationship between poor core stability and injuries of the upper extremity. Tate *et al*. (2009:165) evaluated scapular movement, core muscle endurance (prone bridge and side bridge), and the CKCUEST on 236 young female high school swimmers. This study compared test results between participants with and without reported shoulder pathology. Subsequently, the observation of scapular movement and decreased core endurance both resulted as non-dominating in the shoulder pathology group, except for the decreased side bridge endurance (Borstad *et al*., 2005:227). These results are contradicted by Harrington *et al*. (2014:65), who found no significant differences in core endurance for prone bridge and side bridge in female Division I swimmers.

2.7.1 Neuromuscular control training

Static and dynamic core stability are crucial aspects of posture. NMC is considered as a fundamental outcome of postural orientation (Atkins *et al.*, 2015:1609). Core NMC is grounded on feedback (reactive) control mechanisms (Bird & Stuart, 2012:73). Swimming demands the maintenance of a straight posture, either in the supine or prone position, in an unfamiliar environment. Knowing the inherent 'instability' of a swimmer in water, the larger stress on counterbalancing this perturbation is of great importance to coaches and conditioning specialists.

The position of a neutral spine is pain-free and should be the starting point for core stability training. The neutral position is halfway amid spinal flexion and extension. This is also the position of balance and explosive power for training and sport actions (Bliven & Anderson, 2013:518). Athletes can locate neutral spine position by doing guided pelvic movement exercises. These exercises are performed in a neutral spine with pelvic tilt positions anteriorly and posteriorly, continued in this order, and thereafter brought back to the starting position. Over time, the athlete learns awareness of the neutral position in a proprioceptive manner.

Grounded on the anatomical organisation of the core muscles, local stabilisers are activated earlier than the bigger global stabilisers and mobilisers (Bliss & Teeple, 2005:180). Abdominal hollowing and abdominal bracing exercises are normally used to enhance NMC of the local stabilisers (Akuthota *et al.*, 2008:41). Changed NMC is a contributing component in lower back pain (Tsao *et al.*, 2008:2161). Discerning activation exercises can assist in rearranging the patterns of NMC in the central cortex to enhance core muscle activation (Tsao *et al.*, 2010:1120). Such exercises are executed by placing the index fingers on the deep core muscles located anteriorly, and then "drawing in" (abdominal hollowing) or co-activating (abdominal bracing) the core muscles (Bliss & Teeple, 2005:180).

In addition to intended activation of the local stabilisers, breathing exercises through the diaphragm can enhance core stability. Moreover, the diaphragm aids as the top abdominal border. The stiffening thereof leads to increased IAP and produces a co-activation of the muscles of the pelvic floor (m. pubococcygeus, m. puborectalis, and m. iliococcygeus) and m. transverse abdominis (Bliven & Anderson, 2013:519).

2.7.2 Stabilisation training

Core stability and the concept of balance are critical for almost all types of activities and sports. Even though most sports demand good balance, agility, speed and explosive power, all of them rely on core stability performed in three movement directions (Garrison *et al.,* 2013:753). As soon as volitional tightening of the core stabilisers and proprioceptive consciousness are obtained, stabilisation exercises that enhance muscular strength, endurance, and NMC become the emphasis. Core training emphasises the development of strength and explosive power of both the local and global muscles which work in coordination to stabilise the spine. Running is an action that focusses most on the lower extremity. Inadequate pelvic and trunk muscle stability and strength increases the uncontrollability of the centre of gravity of the body (Garrison *et al.*, 2013:753). Another study hypothesised that a lack of integration in core muscles interrupts the movement of energy (Fredericson & Moore, 2005:25).

The most commonly combined exercises are “the big 3” – curl-up (hip flexor muscles, i.e. m. rectus femoris, m. illiacus, m. psoas, m. illiocapsularis and m. sartorius), side bridge (frontal plane muscles, i.e. m. internal oblique, m. external oblique, m. quadratus lumborum, m. gluteus medius, m. gluteus maximus and tensor fasciae latae) and bird dog (extensor muscles, i.e. m. erector spinae and m. gluteus maximus) (McGill & Karpowicz, 2009:119). Refer to Table 2.1 for clarification of these exercises and designated muscle activation. Other frequently used stabilisation exercises consist of the plank, supine bridge and dead bug (Bien, 2011:271). Ekstrom *et al.* (2007:754) investigated contraction of the core muscles when performing core stability exercises together with hip strengthening exercises and found that these above-mentioned exercises may not mimic sport-specific movements and activities.

Over the years, different training techniques have been established for core stabilisation and are regarded to be successful techniques to strengthen muscles and to improve balance and muscle flexibility, not only in elite athletes, but also in sedentary individuals (Sekendiz *et al.*, 2010:3032). Furthermore, these exercises are broadly used in the planning of training to improve performance. Core muscles are fundamental in optimising balance and athletic performance in lower extremity activities (Imai *et al*., 2014:48) whilst stabilising the spine and trunk when executing lower extremity activities such as jumping and running and upper extremity actions such as throwing (Ozmen & Aydogmus, 2016:566). It is assumed that good core stability will facilitate the force transfer from lower extremities to upper extremities (Konin *et al*., 2003:54).

Following a 9-week core stability programme, Watson *et al*. (2017:25) observed progression in both static and dynamic balance as well as in muscle performance results in dancers’ pivotturning skill, whilst Dello Iacono *et al*. (2014:197) reported improved static and dynamic balance performance in footballers after a 4-week core stabilisation training intervention. Furthermore, Sato and Mokha (2009:133) reported, in a research study using 5000 m running athletes, that 6-week core stabilisation training had no significant outcome on balance performance.

2.7.3 Dynamic functional training

The scientific foundation for established core stability training has recently been reviewed and questioned, particularly with regard to athletic performance. Researchers have reviewed what contributes to the function and anatomy of the core, particularly in the athletic population (Clark *et al*., 2018:2). Clinical research recommends that current core stability training is unsuccessful in the improvement of sports performance. Clark *et al.* (2018:1) also stated that frequently used techniques of determining core stability in research do not include the dynamic character of the core in athletic populations. Recent literature, according to Clark *et al.* (2018:1), has suggested a more dynamic, full body perspective on core stabilisation training, and researchers have started to assess and publish on the effectiveness of these training methods.

Numerous progressions are used in training programmes to change exercise intensities and the difficulty of stability in core training. The suggested progression consists of extremity actions throughout stabilisation exercises, devices used to create unstable surfaces, and sport-specific training that is functional and mimics the sport code.

Stabilisation progression from isometric activations to lower extremity activities improve muscle activation and may better mimic the sport actions (McGill & Karpowicz, 2009:119). The use of instability devices challenges the core musculature and NMC systems (Behm *et al.*, 2010:95). Executing basic strength training exercises (chest press, curl-up and bridge), using a stability ball to create instability, enhances local stabiliser activation and core stability. Furthermore, exercises on a Swiss ball effectively activate an extensive series of core musculature, incorporating local and global stabilisers and global mobilisers (Escamilla *et al.*, 2010:265). Nevertheless, such exercises do not mimic the sport-specific activities (Behm *et al.*, 2010:99).

Spencer *et al.* (2016:613) conducted a study in a functional performance sport setting and suggested a spinal exercise categorisation. The categories included static and dynamic functional exercises focused on spinal movement covering four exercise components, namely motor control, mobility, and strength and work capacity. Both studies explain the extent and character of core stability exercises used in practice and research. However, in athletic populations, the approach to improve dynamic functional core stability by using dynamic functional exercises is unsupported (Spencer *et al*., 2016:624). Table 2.1 shows descriptions as well as the muscles involved when executing core stabilisation exercises.

Table 2.1: Common stabilisation exercises for core stability (Bliven & Anderson, 2013:520)

Exercise	**Description**	**Primary Muscles Activated**
Supine bridge	Supine, knees flexed 90° with feet flat on floor; raise hips to create straight line between shoulder and knees	Gluteus maximus Gluteus medius Longissimus thoracis Lumbar multifidus
Supine unilateral bridge	Perform supine bridge; lift one leg into full knee extension	External oblique Gluteus maximus Gluteus medius Hamstrings Longissimus thoracis Lumbar multifidus
Side bridge	Side lying with upper body supported on forearm with elbow flexed to 90°; lift trunk to create straight line between shoulders and feet	External oblique Gluteus medius Longissimus thoracis Lumbar multifidus Rectus abdominis

Plank	Prone on elbows; lift trunk to create straight line between shoulders and feet	External oblique Gluteus medius Rectus abdominis
Bird dog	Quadruped with neutral spine alignment; can perform unilateral arm/leg raises, progressing to simultaneous contralateral arm/leg raises	External oblique Gluteus maximus Gluteus medius Hamstrings Longissimus thoracis Lumbar multifidus

2.7.4 Stable-surfaced and unstable-surfaced training

Core stability training using unstable surfaces are popular in the health and sporting sectors. Promoters of training on unstable surfaces debate that this kind of training develops neuromuscular paths, resulting in improved strength, explosive power and balance (Parkhouse & Ball, 2011:517). Behm *et al*. (2010:95) specified that an increase in the difficulty of the stability exercise will correspondingly result in an increase of the core muscle activation. For this purpose, resistance exercises on unstable surfaces have been underlined as effective exercises for the improvement of core stability.

Somatosensory reaction, involving the alignment of important body sections, allows ongoing modification of overall posture. This modification is particularly essential in conditions containing unstable surfaces and perturbation. Initially, exercises for the activation and training of core muscles used stable surfaces (Atkins *et al*., 2015:1609). In recent times, unstable-surface exercises with stability balls, suspension straps, or Bosu balls increase the amount of instability. This instability may replicate the fairly unstable environment of the body in sports with an unstable medium such as water (swimming). To date, research on the usefulness of unstable-surface training techniques is limited when associated with more familiar exercises using a stable surface (Atkins *et al.*, 2015:1609). This is predominantly apparent when reviewing current literature involving athletes.

Unstable-surface exercise can encourage variations in the resistance direction, an altering base of support during the course of the movement and the outcome of a stationary point pendulum (Schoffenstall *et al.*, 2010:3422). Behm *et al.* (2010:96) acknowledged that when exercising on unstable surfaces, lesser weight is required for muscle adaptation of the same muscles when compared to exercising on stable surfaces. Additionally, it has been presumed that the subsequent greater coordination demands need more intensive action in the stabilising musculature of the core, which is thought to result in more intensive strength training (Wirth *et al*., 2017:406). Squats on an unstable surface are used in most scientific programmes and commonly detect the electromyography activity of the core musculature and the extensor muscles of the leg (m. rectus femoris, m. vastus intermedius, m. vastus lateralis and m. vastus medialis). The greater the muscle activity observed in a stable surface condition, the greater force has been created and hence an acceptable training stimulus. Regrettably, no research study validates the substantial enhancements in core through exercising on unstable surfaces. Hence, no literature has revealed that exercising on unstable surfaces is better than exercising on stable surfaces (Schoffenstall *et al.*, 2010:3425).

Wahl and Behm (2008:1360) assessed the electromyography activity of the lower abdominal and lumbosacral erector spinae muscles on instability devices and by using stable and unstable exercises in greatly conditioned athletes. The results showed increased muscle activity when standing and squatting on a stability ball and balance board, but no significant changes in muscle activation were noted between exercises on stable and unstable surfaces.

Dwidarti *et al.* (2018:11) investigated the outcomes of core stability training executed on stable surfaces in comparison with training executed on unstable surfaces on athletic performance in school-aged girls. Thirty-six (36) unconditioned healthy females were allocated to a core stability group for training on a stable surface (n=18), or a core stability group for training on an unstable surface (n=18). Both core stability groups were tested before and after the intervention. A 6-week (2 sessions per week) training period was used. Both groups executed the “big 3” exercises (curl-up, side bridge, and quadruped position). During the first two training weeks, participants from both groups executed exercises by performing 3 sets per exercise with 40 seconds of activation or 3 sets per exercise for 20 repetitions. For the next two training weeks, the time of activation was 45 seconds and the repetitions were increased to 23. During the last two training weeks, the activation time was 50 seconds and the repetitions were 25. A rest period of two to three minutes was provided between the executions of exercises. The outcomes of athletic performance were assessed using the 20 m sprint test, stand-and-reach test, Y-balance test, standing long jump test and jumping sideway test. This study demonstrated significant results in improved outcomes of athletic performance in both core stability groups for training on stable and unstable surfaces. The improvement of athletic performance for the unstable group was better compared to that of the stable group.

The above-mentioned results correspond with literature concerning the outcomes of core stability training on athletic performance in young athletes. Following a 6-week core stability training programme (plank oblique's and push-up jacks) on unstable surfaces (stability ball), Allen *et al*. (2014:2063) reported noteworthy performance improvement (f=0.27–0.69) in five different core muscle endurance tests (i.e. Static Curl-up, Dynamic Curl-Up, Parallel Roman Chair Dynamic Back Extension, Lateral Plank, Prone Plank) in healthy unconditioned athletes with a mean age of 20 years. In a randomised controlled trial, Hoshikawa *et al*. (2013:3142) evaluated the outcomes of integrated core stability training on unstable surfaces (side and prone bridging on Swiss ball) and soccer training (interval runs and technical drills) in comparison with only soccer training (interval runs and technical drills) in female field soccer players between the ages of 18 and 22 years. Both intervention groups trained for a period of six months. The results revealed that the addition of stabilisation exercises in soccer training does not improve core stability in female soccer players, but it will strengthen the hip extensors and increase vertical jump performance.

2.7.5 Multi-joint versus single-joint exercises

Various approaches of core stability training are considered as essential for overall health, sports performance, and reducing the risk for injuries (Saeterbakken *et al.*, 2011:718). Both specific core exercises (prone bridge) (Garcia-Vaquero *et al*., 2012:398), as well as multi-joint exercises (squat) are commonly used core stability training (Colado *et al*., 2011:1875).

When considering training specificity, research has suggested that multi-joint resistance exercises may possibly be more appropriate than core exercises performed in isolation due to the fact that they are more similar to sports actions and activities of daily living (Behm *et al*., 2010:97). Research conducted by Behm *et al.* (2010:96) also revealed that a predicted one repetition maximum (1RM) of more than 80% multi-joint resistance exercises (dead lift and squat) can encourage equivalent or greater muscle activation of the core, in comparison with core exercises performed in isolation, more specifically when executed with low to moderate intensities.

Free-weight exercises are considered to increase the core muscles' stability constraint through multi-joint resistance exercises (Saeterbakken *et al.*, 2015:900). Training machines naturally contain a static one-dimensional movement pattern with a reduced amount of core stability requirement in comparison with free-weight exercises which permit two- or three-dimensional movement patterns. Theoretically, free-weight exercises should escalate the ability of the individual to handle the load, and, subsequently, may increase the stimulation of the stabilising muscles more than machine exercises, however, the findings are diverse (Saeterbakken *et al*., 2011:716).

2.8 ATHLETIC PERFORMANCE TRAINING

Many research studies have been carried out focussing on components of athletic performance and how to train each component separately. However, training methods specific to the different sport codes in combination with the demand of skills required in different sport codes have not yet been established. Plyometric exercises were first used in 1960 to train the explosiveness of athletes in preparation for the summer Olympics (Nikseresht *et al*., 2014:383). To date, research studies have proven that plyometric exercises include a form of NMC, which leads to changes in the neuromuscular system and consequently to improvements in muscle strength (Zearei *et al.*, 2013:343). Resistance exercises are also considered as essential for the improvement of agility, speed and explosive power performance due to the changes in the strength of leg extensor muscles (m. rectus femoris, m. vastus lateralis oblique, m. vastus medialis oblique and m. vastus intermedius) (Chelly *et al*., 2010:2670). Thus, it can be seen that all training modalities have an influence on one another and that athletic performance training should include all components, such as agility, speed and explosive power, to improve physical fitness, address the individual needs of each athlete and achieve desirable athletic performance in most sport codes. Zearei *et al*. (2013:343) also agreed that these components should be a prerequisite for the success of athletes, coaches, conditioning staff and rehabilitation specialists.

The training of athletic performance should consider the correct choice of exercises, exercise load (% of 1RM), frequency and volume (days per weeks and weeks per intervention), number of sets and repetitions, rest between sets, tempo, training modalities (NMC, endurance, hypertrophy and explosive power) and order of exercises (Brukner & Khan, 2017:148). Selkow *et al*. (2017:1050) stated that training programmes that focus on neural changes should continue for a period of 4-6 weeks and strength improvements will only be seen after 6-8 weeks of training. Nikseresht *et al*. (2014:385) reported improvements in agility, speed and explosive power performance after an 8-week plyometric and resistance training programme. This could possibly prove that the correct exercise load, frequency and volume were used during the intervention. However, it is still unknown if improvements in the components individually can be transferred to specific sport codes. The latter reflects the research of Fredericson and Moore (2005:670), that athletic performance training should follow the demands of the sport code in order for an athlete to adapt specifically to the imposed demands. Therefore, exercises should be selected with caution when training a specific type of athlete or sport code.

Another aspect to consider when training athletic performance is gender. Nuell *et al*. (2019:10) described that the morphological characteristics of males, such as larger muscle mass, greater number of muscle fibres, taller posture and higher centre of gravity, should be taken into consideration in the design of a programme and that different exercise loads should be used for males and females.

In summary, it is possible to physically enhance the athlete's ability when choosing the correct exercise load and training modalities. Refer to Table 2.2 for a summary of optimal loading exercise guidelines used to choose the relevant training modalities when designing an exercise training programme (Brukner & Khan, 2017:148).

Table 2.2: Summary of the optimal loading exercise guidelines (Brukner & Khan, 2017:148)

Loading Variables	**Training Modalities**		
	Neuromuscular Control	**Strength Endurance**	**Strength Hypertrophy**
Load Magnitude	< 30% of 1RM	30-70% of 1RM	>70% of 1RM
Number of repetitions	>20	15-30	8-12
Number of sets	3-5	3-5	2-4
Rest between sets	Rest = Work	Rest = 1.5 x Work	Rest = 2 x Work
Frequency (days per week)	5	3-5	2-3
Rest between training sessions	12-24 hours	48 hours	48 hours

2.8.1 Agility training

Literature highlights some of the most important components in most sporting events (agility, speed and explosive power) and presents several tests to quantify such performances (Hibbs *et al.*, 2008:1004). Even though this study focuses on agility, speed and explosive power, none of these modalities can be applied without a good foundation of strength. Baechle and Earle (2008:474) stated that muscle strength is the ability to apply force on an exterior object, whereas explosive power is the time it took to exert the force.

Agility enables an athlete to rapidly change direction. For this to happen, the body requires optimal biomechanics and control (Sheppard & Young, 2005:2). Movement in sport requires both leg and arm movement, which require joint and ligament stability as well as a stable base of support in order to optimally produce and transfer forces (Sharrock *et al.*, 2011:64). In order to train agility, running should be performed in multi-plane directions, such as forward, backward, lateral, and diagonal. Therefore, this current study used the T-test to assess agility performance in all directions.

Graham (2017) suggested that a comprehensive agility programme should include the following components, namely strength, explosive power, acceleration, deceleration, coordination, dynamic balance, as well as dynamic flexibility. It is also confirmed that various techniques play a critical role when executing certain exercises, and listed that each one plays a valuable role in correct agility technique: arm action, visual focus, body alignment, deceleration, movement economy, recovery and biomechanics. McGall (2014) suggested that a proper posture is to keep the spine straight and to turn from the hips rather than twisting the spine. Arm action assists in extra speed when the focus is on shoulder movement by driving with the elbows forward and backwards, whereas leg action requires a rapid flexion of the hip with a dorsiflexed foot to drive the leg into the ground (McGall, 2014). The following exercises include all the agility components and techniques and can be used in an agility training programme:

- high knees (forward and lateral);
- cone drills;
- agility ladder drills;
- hurdle drills;
- T-drill;
- L-drill (McGall, 2014);
- agility ball throws;
- balloon drills;
- medicine ball drills (Crockford, 2014).

Kovacikova and Zemkova (2020:1) evaluated the outcome of competitive agility exercises during training on agility performance. Twenty-two (22) athletes participated in this study. Both groups (experimental and control) continued with normal training. Only the EG executed additional agility exercises under competitive conditions for a time period of eight weeks. The time to perform the Agility Dual test, which was performed in pairs, and the Agility Single test, which was performed on their own, was used to assess agility performance before and after the 8-week intervention. A noteworthy difference was reported in the Agility Dual test of the EG ($p=0.002$). Thus, Kovacikova and Zemkova (2020:1) concluded that agility training under competitive conditions leads to better agility performance.

2.8.2 Speed training

Speed is considered as an important factor for better athletic performance. An increase in speed performance leads to an improved physical condition of the athlete. In a study conducted by Mansur *et al.* (2018:357), it has been suggested that a variation of plyometric exercises contributes to increased speed performance. Plyometrics, more familiar as "jump training", are exercises focused on a maximum force generated in muscles in a short time period, with the aim of increasing speed and explosive power. The focus of plyometric training is on the education of muscles to change length in a quick manner, for example with specialised repetitive jumping. The development of explosive power in order to increase the speed of movements is the main goal of the plyometric principle (Mansur *et al*., 2018:357). For this reason, athletic performance cannot be considered in isolation, but as a whole. It is suggested that many modalities, such as strength, speed endurance, explosive power, plyometric, and rhythmic exercises can all contribute to improved speed (Baechle & Earle, 2008:474).

Uthoff *et al*. (2019:1) investigated the efficacy of sled pulling in a forward and backward direction on speed in high school athletes. This kind of resisted sprinting is frequently used in training to improve sprinting speed in youth athletes. Previous literature has only evaluated the outcomes of forward resisted sprint training. This study, conducted by Uthoff *et al*. (2019:1), assessed the outcomes of forward and backward resisted sprinting. One hundred and fifteen (115) high school boys (age 13–15 years) were allocated to either a forward or backward resisted sprinting group. Both groups pulled progressively loaded sleds (20–55% body mass) twice a week for eight weeks. Data were collected pre- and post-training for sprinting times over 10 m and 20 m. The 10 m performance improved significantly in the forward resisted sprinting group, whereas the likelihood of enhancing sprinting performance by training backward resisted sprinting was 10% better than the forward resisted sprinting group. This study concluded that backward resisted sprinting may also enhance sprint performance.

Another method to determine speed performance of athletes was researched by Nuell *et al*. (2019:1). Nuell *et al*. (2019:1) determined whether thigh muscle volumes have an influence on sprinting performance of female national-level sprinters. Thigh muscle volumes were determined by magnetic resonance images of the thighs and sprinting performance was assessed as the time to sprint 40 m and 80 m, respectively. It was concluded that larger muscle volume of the hamstrings led to faster sprinting times and, consequently, speed training programmes should consist of hypertrophy exercises for the quadriceps and hamstring muscles.

2.8.3 Explosive power training

Explosive power production is debatably the most essential component for athletes to develop (Stone *et al*., 2007:3). This statement could be motivated by the fact that, since explosive power is a work-rate, the winner will be the athlete who completes the work at the fastest rate. As seen in the human body, this will be summarised as how fast an athlete is able to contract specific muscles in order to produce fast movements (Sandler, 2005:3). Therefore, as stated by Suchomel *et al.* (2016:1419), muscular strength strongly relates to the rate at which the athlete can develop force resulting in increased explosive power that leads to faster and stronger movements.

The beginning of explosive power development involves the development of a better work capacity and a larger muscle cross-sectional area. A larger exercise intensity of ≥60% of the 1RM is needed to achieve the aforementioned. Although various factors play a role, for a long-standing result, traditional heavy weight-training is required to increase strength, particularly through 1RM assessment. On the other hand, the main focus of traditional dynamic training should be on movement velocity and RFD. Finally, activity-specific high-power training could have a greater effect on athletic performance when compared to traditional heavy weight-training, particularly in those athletes with lower maximum strength (DeWeese *et al*., 2015:308).

Singh *et al*. (2019:1463) analysed the effect of a combined plyometric training and sprint training programme on explosive power (vertical jump) performance in 40 university level sprinters and reported significant changes in explosive power performance. It is recommended that a combined type of training programme can be beneficial for improving athletic performance (Singh *et al*., 2019:1463).

Suna and Kumartasli (2017:117) evaluated the effect of lower extremity strength training (endurance, explosive power and hypertrophy exercise modalities) on vertical jump performance in female university tennis players. Lower extremity strength enables tennis players to get to the ball as quick as possible (Suna & Kumartasli, 2017:117). A significant difference between the pre- and post-vertical jump values was reported after 8 weeks of strength training. It can be concluded that enhancements in lower extremity strength may possibly contribute to improved vertical jump and, consequently, tennis performance.

Shinkle *et al.* (2012:373) conducted a study in order to find a standard field test for the assessment of core musculature and its influence on performance in the athletic sector. Twenty-five (25) Division I football players, participating on collegiate level, executed medicine ball throws in a forward, reverse, left and right direction in both static and dynamic positions. The medicine ball throw performances were compared with seven athletic performance assessments: the CMJ, squat (kilogram per body weight), 1RM squat, bench press (kilogram per body weight), 1RM bench press, 40 m sprint and pro-agility test. Correlations in both positions (static and dynamic) were found with the medicine ball throws and performance assessments. The static positions correlated with the CMJ (r=0.44), 40 m sprint (r=0.5), pro-agility test (r=0.46) and the bench kg/body weight (r=0.42). The dynamic positions correlated with the 1RM squat (r=0.45), 1RM bench (r=0.41) and CMJ (r=0.48). In conclusion, Shinkle *et al*. (2012:373) found that a functional field test, such as the medicine ball throw, improves sport performance in an athletic population.

2.9 CONCLUSION

Sport includes a variety of complex movements. Good biomechanics and body control are required in all sport codes. Various factors such as physical ability (endurance, strength, agility, speed, flexibility, coordination, explosive power, and stamina), talent and motivation have an influence on athletes' abilities to perform optimally (Mansur *et al*., 2018:357). The success in accomplishing training goals is based on various parameters, such as physical exercises, tactics, techniques and mental training.

Sports trainers and experts regard optimal core stability crucial to athletic performance. This evidence-based review argues that, although limited and controversial in evidence, core stability is considered as an important aspect in athletes' ability to perform optimally and to improve their physical condition. Loubser (2018:5) concluded that sport-specific assessments need to be used to provide better definitions of core stability and to determine the correlation of core stability with athletic performance.

Lastly, a battery of valid and reliable tests is needed to compile profiles for both single muscle groups as well as integrated active components of the core. Therefore, this study was performed in order to determine if a relationship exists between core stability and athletic performance by using a variety of core stability tests and athletic performance assessments in different female sports.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION TO METHODOLOGY

This chapter describes the design of this study. An outline is given of the specific population included in the study and the eligibility criteria for female athletes.

In preparation for this study, a literature review was done to determine if a relationship exists between core stability and athletic performance by reviewing a variety of core stability tests and athletic performance assessments in different sports. Relevant publications were searched for in databases such as Kovsiekat, PubMed, EbscoHost, ScienceDirect, as well as applicable academic journals and textbooks, to inform methodological considerations.

The information below describes the research design and the processes followed in the study.

3.2 RESEARCH DESIGN

This was a quantitative, cross-sectional study. The study objective was to determine the relationship between core stability and athletic performance among female university athletes. According to literature, a correlation design is used to determine if there is an association between two or more variables (Thomas *et al.*, 2011:324). Data were collected to determine the importance of core stability in athletic performance and by this, determine the role of core stability training in an overall training programme. Data were gathered via quantitative research (a questionnaire and a data collection sheet – Appendices A and B).

3.3 STUDY POPULATION AND SAMPLE SIZE

According to the Kovsie Sport data base, there were 354 athletes (122 females and 232 males) registered for the 2018/2019 season at the University of the Free State (UFS), representing the first teams in the respective sport codes. The Sport Science Centre on the UFS campus is an exercise facility accommodating all university athletes of the various sport codes. The Kovsie Sport department provides, as part of the sport bursary granted to high performance athletes, training, testing/evaluation and rehabilitation are provided at no cost.

Convenience sampling was used, and all 122 female athletes of the university's first sport teams (Kovsie Sport high performance) were invited to participate in the study.

3.3.1 PARTICIPATION CRITERIA

Athletes were included in the study if they met the following inclusion criteria:

3.3.1.1 Inclusion criteria

- High performance female athlete who represented the University of the Free State in the 2018/2019 season.

3.3.1.2 Exclusion criteria

- Acute injury that was medically diagnosed and required medical treatment during the past three months, which prevented the athlete from executing the tests.
- Illness on the day of testing.
- Unwilling to give consent to participate in any of the tests.

3.3.1.3 Withdrawal of study participants

- If the participant sustained an injury during the testing, the athlete was withdrawn from the study.

In the case of an adverse event, first aid was offered at the Sport Science Centre at no cost. The first aid coordinator of the University of the Free State, Ms Paula Anley, along with her first aid assistants, were present on the day of testing.

3.4 TESTING PROCEDURE

Testing took place at the University of the Free State Sport Science Centre. The testing procedure was for a duration of one hour and was assisted by the following:

- A registered Biokineticist (researcher) – body composition
- A registered Biokineticist (researcher) – core stability testing
- Six Biokinetic interns – athletic performance testing
- A registered Biokineticist (researcher) – capturing data

All assistants involved in the tests received training from the researcher, a registered Biokineticist and a researcher in the specific field, and the researcher, Marizanne de Bruin, in order to understand and perform the tests correctly. Assistants were tested after training to determine if they were capable of assisting with the tests. Each assistant had to obtain a Level Two Basic Life Support certificate, stating that they completed the course in order to assist in case of an adverse event.

3.4.1 DATA COLLECTION

In this study, data were collected using questionnaires as well as the performance of individual testing procedures to determine core stability and athletic performance.

Testing of the different sport teams took place on different days as part of their periodization in the off-season and preseason. Participants were tested in groups of 20-30, depending on the size of each team. On the day of testing, before any procedures took place, all tests and procedures were verbally explained by the researcher, Marizanne de Bruin, to each participant at the Sport Science Centre. Before testing commenced, each participant received an information letter (Appendix D) which explained the procedures to be followed. Informed consent had to be given by each participant before any testing took place (Appendix E).

The different sport teams were informed a week before testing that, on the day of testing, they were not allowed to do any exercises or eat less than three hours beforehand.

3.4.1.1 Testing procedure

On the day of arrival at the Sport Science Centre, each participant completed a questionnaire provided by the researcher which consisted of the following information:

- Demographic and personal information: participant number, date of birth, age and gender (Appendix A).

- Information on the athlete's sport profile: level of sport, type of sport, position played in the sport and any previous or current injuries (Appendix A).

Refer to Figure 3.1 for the data collection process.

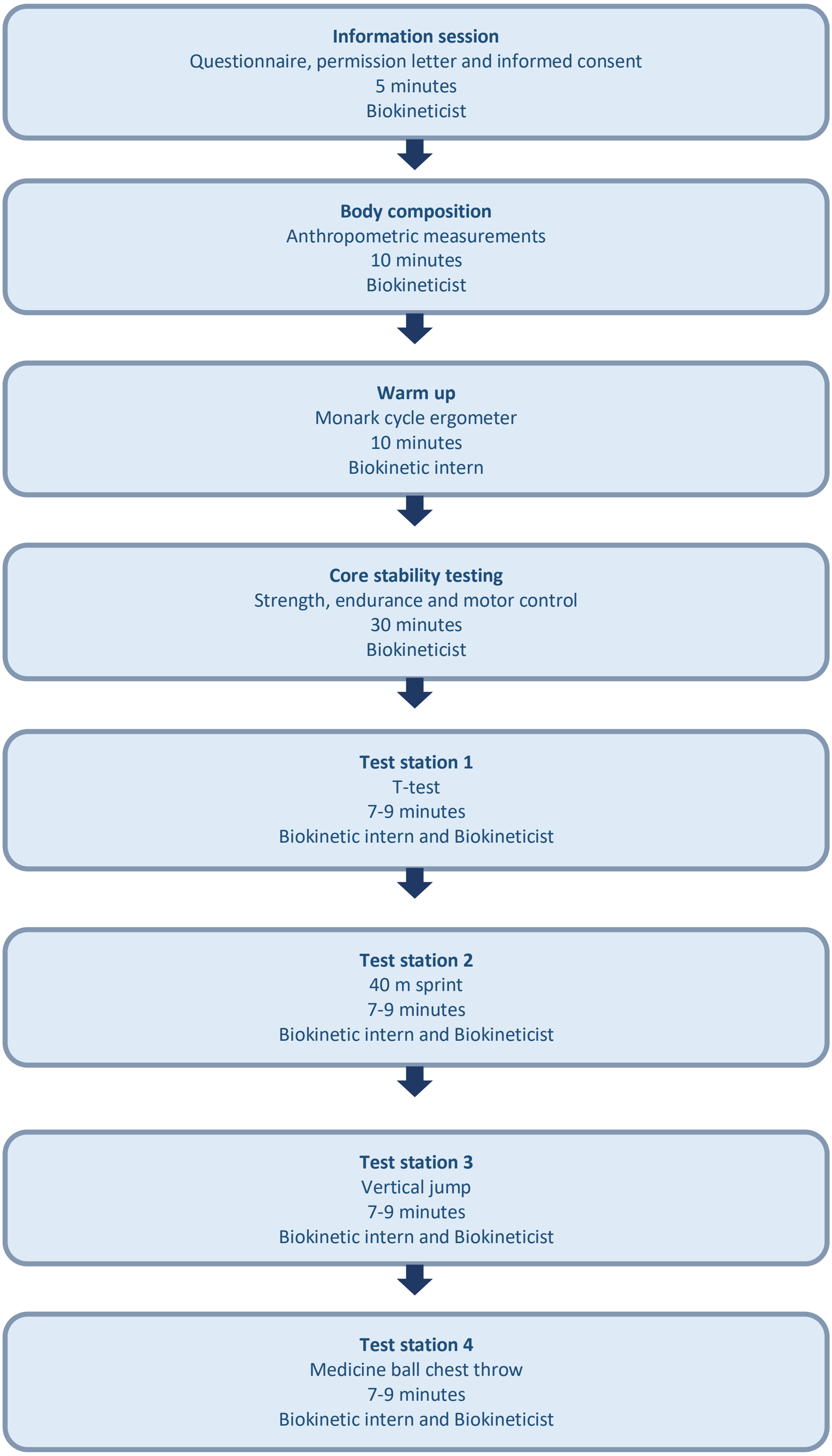

Figure 3.1: Schematic representation of the data collection process

3.4.2 ASSESSMENTS

To ensure reliability in this study the apparatus used for the assessment of core stability and athletic performance was consistently the same and was tested by the same researcher. The Sport Science Centre provided all assessment equipment.

3.4.2.1 Anthropometric characteristics

All anthropometric measurements and circumferences were conducted by the researcher. Measurements were conducted in one of the evaluation rooms in the Sport Science Centre. Privacy was maintained with only the researcher and the participant present in the evaluation room. Participants were instructed beforehand to wear short pants and a short shirt that the participant could pull up without the need to undress. The measurements were taken on the right side of the body in an upright standing position, with the exception of the front thigh skin fold, which was taken in a sitting position (Marfell-Jones *et al.,* 2006:5).

The International Standards for Anthropometric Assessment (ISAK) method was used to determine the athlete's body composition. Height was measured to the nearest 0.1 cm using a stadiometer calibrated to the nearest 0.1 cm (Seca 225, Seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kilogram (kg) on a digital scale (Seca, Hamburg, Germany) with the subject wearing lightweight clothing and no shoes. The height and weight measures were taken three times and followed the guidelines of the ISAK (Stewart *et al*., 2011). BMI was calculated as weight in kilograms divided by height in metres squared ($kg.m^{-2}$) and, accordingly, participants were classified into normal (BMI < 25 $kg.m^{-2}$), overweight (BMI: 25-29.9 $kg.m^{-2}$) and obese (BMI ≥ 30 $kg.m^{-2}$). Waist circumference was measured using a flexible steel tape (Lufkin W606PM, Creative Health Products, MI, USA) to the nearest 0.1 cm. The waist circumference measurements were categorised into normal (< 88 cm) and elevated (≥ 88 cm). Measurements were taken with participants standing, on the midpoint between the lower edge of the costal border and the upper edge of the iliac crest. All measurements were taken three times by the same trained person (Biokineticist and researcher) with the mean of the two closest assessments used for analysis. Skinfolds were measured using a Harpenden skinfold calliper to the nearest 0.1 millimetre (mm). To minimise discrepancy between two assessments, a permanent marker was used by the Biokineticist (researcher) to indicate the anatomical landmarks on the skin which indicated where the skinfold measurement was to be taken. This served as a guide for calliper placement to ensure consistent measurements. The researcher individually measured each athlete. In order to determine the participant's somatotype, a bone breadth calliper was used to measure the breadth of the humerus and femur to the nearest 0.1 mm.

Table 3.1 describes the procedure followed when measuring the six skin fold measurements that were taken. The maximal calf and bicep circumferences and the circumferences of the waist and hips for calculation of estimated BF% were also measured.

Table 3.1: Skinfold measurement sites (Marfell-Jones *et al*., 2006:24-48)

Site of measurement	**Definition**	**Subject position**	**Location**
Triceps (Figure 3.2)	The most posterior part of the triceps when viewed from the side at the marked mid-acromial-radial level.	When marking the sites for the triceps skin fold, the subject assumed the anatomical position.	Used a measuring tape to locate the mid-point between the acromion process and lateral radial head.
Subscapulare (Figure 3.3)	The site 2 cm along a line running laterally and obliquely downward from the subscapular landmark at a 45° angle.	The subject assumed a relaxed standing position with the arms hanging by the side.	Used a measuring tape to locate the point 2 cm from the subscapulare in a line 45° laterally downward.
Iliocristale (Figure 3.4)	The site at the centre of the skinfold raised immediately above the marked iliocristale.	The subject assumed a relaxed position with the left arm hanging by the side and the right arm abducted to a horizontal position.	This skin fold was raised immediately superior to the iliac crest. The measurer aligned the fingers of the left hand on the iliac crest landmark and exerted pressure inwards so that the fingers roll over the iliac crest. Then the left thumb was substituted for these fingers and the index finger was

			relocated a sufficient distance superior to the thumb so that this grasp became the skin fold to be measured. The measurer then marked the centre of the raised skin fold. The fold ran slightly downwards anteriorly as determined by the natural fold of the skin.
Abdominal (Figure 3.5)	The site 5 cm to the right-hand side of the omphalion (midpoint of the navel).	The subject assumed a relaxed standing position with the arms hanging by the side.	This was a vertical fold raised 5 cm from the right-hand side of the omphalion.
Front thigh (Figure 3.6)	The site at the midpoint of the distance between the inguinal fold and the anterior surface of the patella on the midline of the thigh.	The subject assumed a seated position with the torso erect and the arms hanging by the side. The knee of the right leg should be bent at a right angle.	The measurer stood facing the right side of the seated subject on the lateral side of the thigh. The site was marked parallel to the long axis of the thigh at the midpoint of the distance between the inguinal fold and the superior margin of the anterior surface of the patella (whilst the leg was bent). The inguinal fold was the crease at the angle of the trunk and the thigh. If there was difficulty locating the fold the subject flexed the hip to make a

			fold. The measurer placed a small horizontal mark at the level of the midpoint between the two landmarks and then drew a perpendicular line to intersect the horizontal line. This perpendicular line was located in the midline of the thigh. If a tape was used be sure to avoid following the curvature of the surface of the skin.
Medial calf (Figure 3.7)	The site on the most medial aspect of the calf at the level of the maximal girth.	The subject assumed a relaxed standing position with the arms hanging by the sides. The subject's feet were separated with the weight evenly distributed.	The level of the maximum girth was determined and marked with a small horizontal line on the medial aspect of the calf. The maximal girth was found by using the middle fingers to manipulate the position of the tape in a series of up or down measurements to determine the maximum girth. The measurer viewed the marked site from the front to locate the most medial point and marked this with an intersecting vertical line.

Figure 3.2: Triceps skinfold (Marfell-Jones *et al*., 2006:63)

Figure 3.3: Subscapulare skinfold (Marfell-Jones *et al*., 2006:64)

Figure 3.4: Supraspinale skinfold (Marfell-Jones *et al*., 2006:67)

Figure 3.5: Abdominal skinfold (Marfell-Jones *et al*., 2006:68)

Figure 3.6: Thigh skinfold (Marfell-Jones *et al*., 2006:70)

Figure 3.7: Medial calf skinfold (Marfell-Jones *et al*., 2006:71)

The anatomical landmarks and related skin folds were carefully taken to find the correct location, as guided by Marfell-Jones *et al.* (2006:5). BF% was calculated using the Carter equation: BF% = (sum of the 6 skin folds X 0.1548) + 3.58 (Withers *et al*., 1987:167). The BF% was categorised into essential fat (10-13%), athletes (14-20%), fitness (21-24%), average (25-31%) and obese (≥ 32%) (Muth, 2009).

3.4.2.2 Core stability testing

The researcher conducted all the core stability tests.

i. Core strength tests

As described by Saeterbakken *et al*. (2015:56), core strength of the global core muscles was assessed using the Bering-Sorensen tests, which included an isometric back extension (IBE) test, lateral flexion (LF) test and abdominal flexion (AF) test. Maximal effort was used to assess core strength. The strength was assessed at a maximum volunteered contraction for a duration of three seconds. A Tendo Sports Machine was used to assess the explosive power output of the maximum volunteered contraction. Each of the three respective core strength tests were performed three times with a one-minute rest in-between each attempt and three minutes rest before performing the next test. The greatest mean force output, in Newton (N), over three seconds for each test (IBE, LF and AF) was used in further analyses. When training core strength, heavy weight should be used with only 3-6 repetitions in order to create increased pressure in the muscles of the core (Saeterbakken *et al.*, 2011:717).

The Bering-Sorensen IBE test (Figure 3.8) was assessed in a prone position on an exercise bed. The participant had to hold a prone position until failure (Tse *et al.*, 2005:548). The edge of the iliac crest was positioned on the tip of the bed whilst the arms were crossed over the chest. Lastly, the body was in a straight position with the feet secured to the bed by the ankles (Tse *et al.*, 2005:548).

During the LF test (Figure 3.9), the participant lay horizontally, with their legs and hip relaxing on the bed. The participants were not allowed to rest on their elbows whilst their feet were tied with a strap to the bed across their ankles. Only the dominant side was assessed (facing upwards) and the non-dominant arm was crossed over their chest (Saeterbakken *et al.*, 2015:56).

For the AF test position, the participant had to hold a 45° angle between their hips and the bed and bend the hips and knees 90° (Figure 3.10). The spine had to be held upright whilst crossing the arms over their chest with their feet secured to the bed (Tse *et al.*, 2005:549).

Figure 3.8: The test set-up for the Bering-Sorensen IBE test (Saeterbakken *et al*., 2015:56)

Figure 3.9: The test set-up for the LF test (Saeterbakken *et al*., 2015:56)

Figure 3.10: The test set-up for the AF test (Saeterbakken *et al*., 2015:56)

ii. Core endurance tests

The exact same positions and tests, as performed to assess the core strength of the global muscles, were also used to assess core endurance of the global muscles. The Bering-Sorensen method reports a reliability coefficient of 0.97-0.99 (Tse *et al*., 2005:548). The time the participant was able to uphold the test position was recorded using a stopwatch. All tests were terminated when the participant fell below the test position. Core endurance has been used for lower back pain patients in avoiding injury and in rehabilitation situations (Saeterbakken *et al*., 2015:56).

iii. Core motor control tests

Core motor control was assessed using a Welch Allyn FlexiPort pressure biofeedback unit to assess changes in pressure as the local and global core muscles aimed to stabilise the trunk during low load limb movement. Von Garnier *et al*. (2009:9) reported an ICC of 0.91 for test-retest reliability of the pressure biofeedback unit.

The Wisbey-Roth Core Stability Grading System, according to Wisbey-Roth (1996) (Figure 3.11), was used to classify the motor control component of core stability. The participant lay in a supine position on an exercise bed. A pressure biofeedback unit was placed below the lower back and inflated to 40 millimetres of mercury (mmHg). The participant was given instruction to maintain the pressure on the gauge whilst performing various lower extremity movements. Participants were instructed to breathe regularly. Changes in the pressure greater than 10 mmHg were indicative of diminished core motor control. The next level was only described after the previous level was successfully completed. Each activity level represented a level of core motor control (Mills *et al*., 2005:62-63). The participant was allowed one trial on each level and was only progressed to the next level after successful core motor control of the previous level. Scoring was the highest completed level where the instructed task was successfully completed with a change of less than 10 mmHg on the pressure biofeedback unit with a normal breathing pattern (Roussel *et al*., 2009:1070). Refer to Figure 3.11, to follow, for a schematic representation of the core stability grading system used in this current study.

Grade 0	Unable to maintain an isometric contraction without compensatory movement of the core (ie. L/S and pelvis) in a position aimed to facilitate the stabilising role of key muscles.
Grade 1	Able to maintain an isometric contraction (10 to 20 seconds) without compensatory movement of the core (ie. L/S and pelvis) in a position aimed to facilitate the stabilising role of key muscles.
Grade 2	Able to maintain an isometric contraction (for 20 seconds) without compensatory movement of the core with superimposed slow movement of the limbs.
Grade 3	Able to maintain an isometric contraction (for 20 seconds) without inappropriate movement of the core while performing slow movements of the trunk itself.
Grade 4	Able to maintain an isometric contraction (for at least 20 seconds) without compensation /inappropriate movement of the core while performing fast movements of the limbs.
Grade 5	Able to maintain an isometric contraction (for at least 20 seconds) without compensation/inappropriate movement of the core while performing:- a) fast movements of the trunk - if appropriate to activity required, with joint angle specific positioning and muscle function specifc. b) fast movements of the limbs in joint angle specific postures and muscle function specific (ie. reproducing concentric/eccentric role of key stabilisers) c) against increased resistance/increased load in joint angle specific postures and muscle function specific positioning, which are sport/activity specific.

Figure 3.11: Schematic representation of the Wisbey-Roth core stability grading system (Wisbey-Roth, 1996)

3.4.2.3 Athletic performance testing

i. Agility test

The agility T-Test was used for assessment of the athletes' agility performance (Figure 3.12). The T-test was conducted by a Biokinetic intern to assess the athletes' agility performance in a forward, backward and lateral direction. The T-test is a running test that assesses agility and quickness. The agility and direction changes performed during a T-test are used in a wide variety of sport codes with an ICC of 0.97 (Huggins *et al.*, 2017:74). Optimal agility is critical to complete the course and change direction within the shortest amount of time (Sharrock *et al.*, 2011:68).

The time of the T-test (in seconds) was recorded using a stopwatch. Four cones were used as markers for the T-test. On the cue of the timer, the participant sprinted 10 m from the start (A) in a forward direction to touch the base of cone B, then side shuffled 5 m to the left to touch the base of cone C. The participant then changed direction to the right and shuffled 10 m to touch the base of cone D, changed direction again to the left and shuffled 5 m to touch the base of cone B and then ran 10 m backwards to the start (A). Time was stopped when they passed cone A. The participants were allowed to perform a practice trial to familiarise themselves with the test. After the trial, the actual test started.

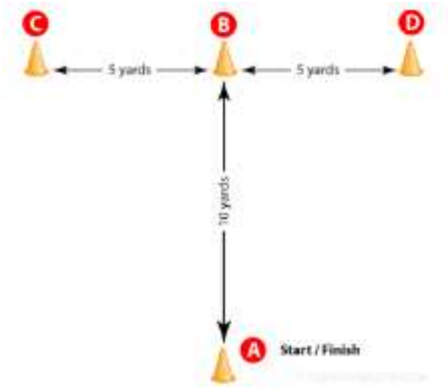

Figure 3.12: Schematic representation of the T-test (Wood, 2008a)

The trial did not count if the participants crossed their feet whilst shuffling or fell during the test. The participants completed three rounds and the best time to the nearest 0.1 seconds was noted on a scoring sheet (Appendix B) by the Biokinetic intern. A rest period of two minutes was provided and recorded by the researcher, after which the participant moved to the next testing station.

ii. Speed test

The 40 m sprint test was used to assess the athlete's lower extremity explosive power and speed (Haugen *et al.*, 2014:432). Forty (40) metre sprint trials have a high ICC of 0.85 (Reina *et al.*, 2017:6). The athlete was instructed by a Biokinetic intern to cover a distance of 40 m as fast as possible (Figure 3.13). Cones were used to mark the distance. The time was recorded by the Biokinetic intern since the first movement of the extremities and terminated when the participant crossed the line. The participants completed three rounds where after the fastest time to the nearest 0.1 seconds was noted on a scoring sheet (Appendix B) by the Biokinetic intern.

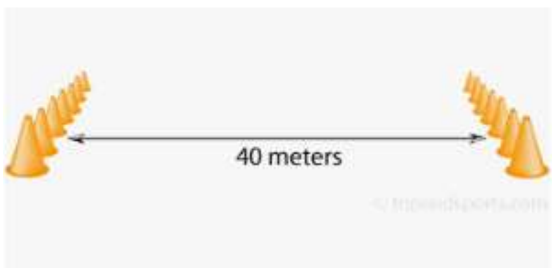

Figure 3.13: Schematic representation of the 40 m sprint (Wood, 2008b)

iii. Lower extremity explosive power

To determine athletic performance, the vertical jump was used to assess lower extremity explosive power. Sports, for example netball, soccer and tennis, require good explosive power of the lower extremities in order to jump specific heights. The Vertec was used in order to determine the distance of the vertical jump (Figure 3.14). It is stated in literature that measuring the vertical jump using the Vertec is one of the most valid and reliable tests with an ICC value of 0.99 to determine the explosive power of the lower extremities (Hutchison & Stone, 2009:8).

Figure 3.14: Schematic representation of the vertical jump (Wood, 2010)

Each participant was granted a practice trial to ensure they understood how to perform the movement. The participant stood facing the wall and reached up with both hands. The standing reach distance was recorded at the top of the fingertips whilst the participant stretched their arms above their head, keeping their feet flat on the ground. The participant was instructed by a Biokinetic intern to stand perpendicular to the Vertec with their body weight equally spread between the legs and feet with the dominant side facing the wall. The participant was not allowed to perform a double bounce before the jump. The participant was allowed to bend the knees and then jump from both feet as high as possible and touch the Vertec with the dominant hand. The participants completed three trials and the best height to the nearest 0.1 cm was noted on a scoring sheet (Appendix B) by the Biokinetic intern. The participant rested for two minutes to ensure optimal recovery and then shifted to the next testing station.

iv. Upper extremity explosive power

The medicine ball chest throw was used to assess upper extremity strength and explosive power (Figure 3.15) (Sharrock *et al.*, 2011:68). Sayers and Bishop (2017:311) stated that the reliability of the medicine ball throw is 0.87-0.95. Many sports require overhead activities like throwing a ball or catching an object. Hence, athletes need a good level of upper extremity explosive power for optimal performance during these movements (Sharrock *et al*., 2011:68).

Figure 3.15: Schematic representation of the medicine ball chest throw (Baker, 2014)

For the completion of this test the participant was instructed by a Biokinetic intern to stand/sit in a kneeling position with knees bent 90° and both hips in full extension. A distance of 10 m was measured out using a measuring tape. The 3 kg medicine ball was held with both hands in front of the chest. When the participant was ready, they could throw the ball vigorously as far forward as possible without falling forward or rocking back to gain momentum before the throw. Each participant was granted a practice trial to ensure they understood how to perform the movement. If the movement was carried out properly without compensatory or trick movements, the distance of the first bounce was measured. The participants completed three trials and the best distance to the nearest 0.1 m was noted on a scoring sheet (Appendix B) by the Biokinetic intern.

After completion of all five tests, the score sheets were collected from the participants. Data sheets were reviewed to ensure that participants completed all the tests and the data were logged in on an Excel spreadsheet by the researcher.

3.5 METHODOLOGICAL AND ASSESSMENT ERRORS

According to literature, validity is the degree to which the test or study is able to assess what it should assess (Reiman & Manske, 2009:4). Test protocols and regulations were followed for speed, explosive power, agility and core testing, as set out by Sharrock *et al.* (2011:67). When performing clinical and functional testing and assessments, the researcher had to be cautious when performing each test. Many factors had to be considered when testing agility, speed, and explosive power. Factors that may influence results were: exercise on the day or few days prior to testing, time of the day that the testing takes place, sequence of testing, inconsistencies in the use of rules and regulations during data gathering, insufficient rest between each test, or inexperience of the researcher and poor knowledge/technique (Baumgartner *et al.*, 2006:72). For the aforementioned reasons, the researcher made sure to inform all participants when inviting them to participate to rest the day prior to testing. The researcher was also responsible for making sure that all the research assistants understood the rules and regulations of each test and strict guidelines had been used when the tests were conducted. There was enough time for rest given between the different testing stations to ensure optimal results and all tests were performed in the morning (06:00-08:00) whilst the participants were still energised. To warrant internal reliability, each participant completed each test three times to ensure good and reliable results.

Lack of sleep and calorie intake may have an effect on muscle fatigue. Participants were instructed to have a good night's rest of at least eight hours of sleep and a balanced calorie intake (a healthy meal consisting of all nutrients) not less than three hours before data collection (Appendix B).

3.6 DATA ANALYSIS

Data were captured electronically by the researcher on Microsoft Excel (Microsoft Office 2016). Any further analysis was performed by Professor Robert Schall using SAS (SAS, 2017).

3.6.1 Data

Data on core stability, namely strength (IBE_S, LF_S, AF_S), core endurance (IBE_E, LF_E, AF_E), and core motor control (NMC), and for the four tests of athletic performance (40 m Sprint, T-Test, Vertical Jump and Medicine Ball Chest Throw) were available for 83 of the 122 pre-determined female athletes from different types of sport codes, together with the demographic variables, namely age, weight, height, BMI and BF%. Thirty-nine (39) of the 122 female athletes did not meet all the participation criteria for testing. More data on injuries (yes/no) were available for the athletes for various body systems.

3.6.2 Analysis Objective

The primary objective of the analysis was to determine whether core strength, endurance and motor control correlated with athletic performance and body measurements in female athletes. Secondary objectives were to assess whether core strength, endurance and motor control correlated with athletic performance and body measurements differently between the various sport codes.

3.7 STATISTICAL ANALYSIS

The statistical analysis was performed by Prof R Schall of the Statistical Consultation Unit, Department of Mathematical Statistics and Actuarial Science, University of the Free State. The data were analysed using the SAS statistical software package (SAS, 2017).

Generally, when statistical hypothesis tests were carried out, a P-value smaller than 0.05 was considered statistically significant.

3.7.1 Descriptive Statistics

All quantitative variables were summarised using descriptive statistics (mean, standard deviation (SD), minimum, quadrant 1 (Q1), median, quadrant 3 (Q3) and maximum), both overall and by type of sport. Categorical variables (injury: yes/no) were summarised by frequency tables and percentages, both overall and by type of sport.

3.7.2 Correlations

Correlation coefficients and associated P-values were calculated between analysis variables, as follows:

- Overall for all participants
- Separately for each sport

3.7.3 ANOVA

Core stability, athletic performance and body measurements were compared between sports using one-way ANOVA, fitting sport as categorical variable in the model. For each variable analysed, the overall F-test for sport was reported, as well as the η^2 effect size measure for ANOVA. Furthermore, a "lines" display is presented indicating the statistically significant differences between the various sports.

Core stability, athletic performance and body measurements were also compared between injured (any injury) and non-injured (no injury) athletes using one-way ANOVA, fitting injury as categorical variable in the model. For each variable analysed, the overall F-test for injury was reported, as well as the η^2 effect size measure for ANOVA.

3.7.4 Effect of core stability on athletic performance: ANCOVA

The effect of core stability on athletic performance was assessed using ANCOVA. Since type of sport and the various demographic variables potentially also affect athletic performance, the ANCOVA model fitted to each assessment of athletic performance as dependent variable (40 m Sprint, T-Test, Vertical Jump and Medicine Ball Chest Throw) included the following independent variables:

- Age, height, weight, BMI, BF% and sport

Furthermore, the characteristics of core stability were fitted as independent variables in the model:

- IBE (Strength), LF (Strength), AF (Strength), IBE (Endurance), LF (Endurance), AF (Endurance), and NMC

Initially, the full ANCOVA model was fitted, namely all independent variables listed above.

Furthermore, backward model selection was performed as follows: starting with the full model fitting all the above variables, at each selection step, that variable was chosen for exclusion from the model whose exclusion from the model achieved the largest increase in the Schwarz Bayesian Information Criterion (SBC). The SBC was chosen as model selection criterion because in our experience it generally led to the most parsimonious model (model with fewest variables), thus reducing the potential of model over-fit.

For each assessment of athletic performance, the results of the full model and of the final model selected by the SBC are reported here, together with estimates of the regression slopes and associated P-values.

3.8 PILOT STUDY

Thomas *et al*. (2011:278) states that it is important to conduct a pilot study to identify potential problems or drawbacks in the proposed technique. This process is called a pilot study. Van Teijlingen *et al*. (2001:289) reported that the reason for a pilot study is for pre-assessment of the research instruments. A pilot study was planned as soon as the researcher received ethical clearance. The pilot study was implemented and included seven core stability tests and four athletic performance tests. The pilot study identified possible difficulties or drawbacks in the suggested assessments. By conducting this pilot study, the researcher addressed questions regarding the procedure of the main study, such as the number of research assistants, assessment processes and validity of assessment equipment. During the pilot study the researcher tested ten voluntary participants taking part in sport for the University of the Free State. The pilot study results were not included in the final research.

3.9 ETHICS APPROVAL

Before enrolment of any participants and commencement of the study, consent was attained from the following:

- Director of Kovsie Sport: Mr D.B. Prinsloo (Appendix E);
- Head of the Department of Exercise and Sport Sciences: Professor D. Coetzee (Appendix F);
- Dean of the Faculty of Health Science: Professor G. van Zyl;
- Dean of Student Affairs: Professor P. Mgolombane;

- Vice Rector of Research: Professor C. Witthun;
- Health Sciences Research Ethics Committee (HSREC) of the Faculty of Health Science at the University of the Free State (Appendix G).

Ethics approval was obtained from the HSREC under the following ethics clearance number: UFS-HSD2019/0447/2506 (Appendix H).

CHAPTER 4

RESULTS

4.1 INTRODUCTION

The purpose of this study was to investigate the relationship between core stability, which includes core strength, core endurance and core motor control, as well as athletic performance measures, namely the (1) 40 m Sprint test, (2) T-test, (3) Vertical jump test and the (4) Medicine ball chest throw test. Data were collected from 83 female university athletes playing hockey, netball, running (athletics), soccer and tennis during the 2018/2019 sport season who met all the participation criteria. This chapter will present the results of the study. The interpretation and the discussion of the findings will follow in Chapter 5.

4.2 STUDY PARTICIPANTS AND ANTHROPOMETRIC CHARACTERISTICS

4.2.1 Participants

One hundred and twenty-two female university athletes were registered for the 2018/2019 sport season. Thirty-nine (32%) athletes did not qualify for testing due to injuries they sustained within the last three months. Therefore, 83 of the 122 athletes (68%) were tested. Table 4.1 presents the number of female athletes by sport.

Table 4.1: Number of female athletes by sport

	Hockey	Netball	Runner	Soccer	Tennis	Total
Total	24	16	11	15	17	83
% Total	29%	20%	13%	18%	20%	100%

4.2.2 Descriptive statistics for anthropometric characteristics

The demographic information displayed in this section provides an overview of the cohort of athletes. The age of athletes in the sample ranged from 18–25 years, with a mean of 20.41 (±1.44) years. The height of athletes ranged from 1.54 – 1.88 m, with a mean of 1.68 m (±0.06), whilst the weight ranged from 51.2 – 85 kg, with a mean of 63.05 kg (±7.09). With regard to the percentage of body fat (BF%), the athletes in the sample ranged from 15.09 – 35.72%, with a mean of 21.95% (±3.29), whilst the BMI of athletes ranged from 17.71 – 35 kg.m^{-2}, with a mean of 22.29 kg.m^{-2} (±2.42).

Table 4.2 shows the descriptive statistics for the five anthropometric characteristics overall, and by the type of sport. Box plots illustrate the distribution of the variable that is plotted. The data boxes display the range from the first to the third quartile of the data, and thus represent the central 50% of the data. The whiskers attached to the boxes are drawn from the box to the most extreme point that is less than or equal to 1.5 times the inter-quartile range (IQR) (IQR: the difference between the third and first quartile). If the highest or lowest values are more than 1.5 times the IQR from the box, they are represented by a "+" or a "o" sign. Figures 4.1 – 4.2 present box plots of the variables, namely age, height, weight, and BMI of female athletes by the type of sport code.

Table 4.2: Descriptive statistics for anthropometric characteristics: Overall and by type of sport (Table 4.2 continues on next page)

		All Sports	Hockey	Netball	Runner	Soccer	Tennis
Age [yr]	**N**	**83**	**24**	**16**	**11**	**15**	**17**
	Mean	20.41	20.42	19.94	19.67	21.47	20.45
	Std	1.44	1.32	1.29	1.05	1.70	1.13
	Min	18.00	18.00	19.00	18.00	19.00	19.00
	Q1	19.00	19.00	19.00	19.00	20.00	19.00
	Median	20.00	20.00	20.00	20.00	21.00	21.00
	Q3	21.00	21.50	20.00	20.00	23.00	21.00
	Max	25.00	23.00	23.00	22.00	25.00	22.00
Height [m]	**Mean**	1.68	1.67	1.69	1.70	1.68	1.66
	Std	0.06	0.06	0.05	0.07	0.05	0.03
	Min	1.54	1.54	1.61	1.62	1.63	1.59
	Q1	1.65	1.66	1.65	1.66	1.66	1.65
	Median	1.68	1.68	1.68	1.69	1.67	1.67
	Q3	1.70	1.70	1.71	1.71	1.68	1.68
	Max	1.88	1.85	1.82	1.88	1.85	1.69

Weight [kg]	**Mean**	63.05	63.69	66.40	58.25	63.68	62.36
	Std	7.09	7.51	8.61	6.68	5.30	2.97
	Min	51.20	51.20	51.60	51.80	55.40	57.20
	Q1	58.50	59.50	61.10	52.60	60.20	60.50
	Median	62.20	62.15	64.00	55.10	63.50	63.20
	Q3	68.00	69.55	72.20	62.00	66.20	64.00
	Max	85.00	83.00	85.00	72.80	74.80	68.00
Body fat [%]	**Mean**	21.95	22.37	24.09	18.47	22.47	21.87
	Std	3.29	3.10	3.62	2.07	2.53	2.15
	Min	15.09	17.95	21.08	15.09	18.58	19.44
	Q1	19.85	20.82	22.01	16.06	20.84	20.60
	Median	21.52	21.41	23.10	18.56	22.05	21.55
	Q3	23.60	23.68	24.55	19.82	23.60	22.52
	Max	35.72	34.13	35.72	22.37	27.79	26.80
BMI [kg.m^{-2}]	**Mean**	22.29	22.78	23.20	20.09	22.49	22.59
	Std	2.42	3.16	2.13	1.75	1.50	1.14
	Min	17.71	19.52	19.86	17.71	19.86	20.27
	Q1	20.60	20.91	21.46	18.82	20.98	21.96
	Median	22.06	21.70	23.23	20.10	22.73	22.66
	Q3	23.58	23.62	25.18	21.19	23.54	23.51
	Max	35.00	35.00	26.30	24.46	24.71	24.38

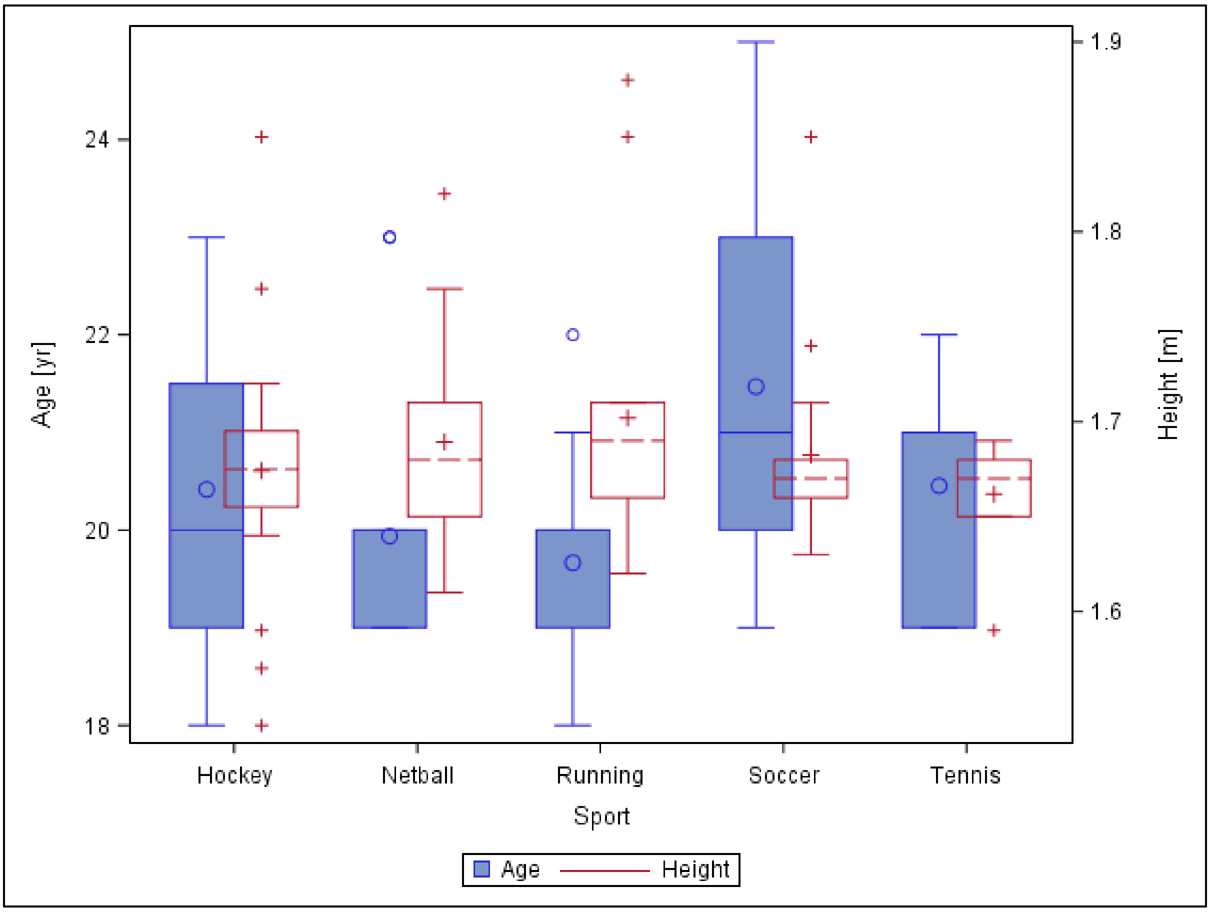

Figure 4.1: Box plot: Age and height anthropometric characteristics by type of sport

Figure 4.1 suggests that the age of the athletes is similar for hockey and tennis and likewise for netball and running. However, netball and running have notably lower values of age compared to the other sport codes, with the upper quartile of the distributions being lower than or similar to the lower quartile of the distribution for soccer (Table 4.2). Soccer (21.47 yr) had the highest mean value for age and running the lowest (19.67 yr) (Table 4.2). Hockey (20.42 yr), netball (19.94 yr) and tennis (20.45 yr) had similar mean values for age.

Similarly, Figure 4.1 also suggests that the height of the athletes is similar for hockey, netball and running, and likewise for soccer and tennis. However, soccer and tennis have notably lower values of height than the other sports, with the lower quartiles of all the distributions being similar (Table 4.2). Running (1.70 m) had the highest mean value for height and tennis the lowest (1.66 m) (Table 4.2). Hockey (1.67 m), netball (1.69 m) and soccer (1.68 m) had similar mean values for height.

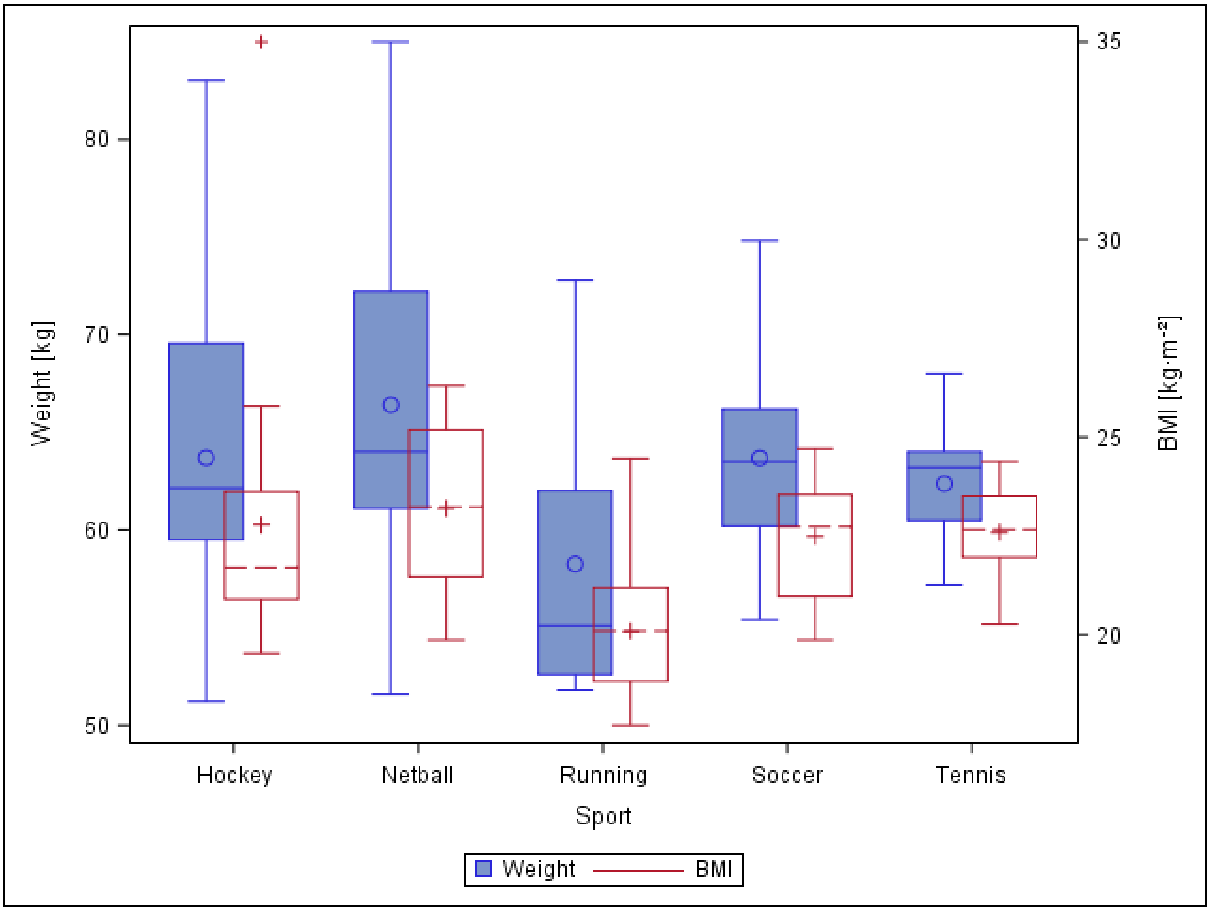

Figure 4.2: Box plot: Weight and BMI anthropometric characteristics by type of sport

Figure 4.2 suggests that the weight of the athletes is similar for hockey, soccer and tennis. However, running has notably lower values for weight than the other sports, with the upper quartile of the distribution being similar to the lower quartile of the other distributions (Table 4.2). Netball (66.4 kg) had the highest mean value for weight and running the lowest (58.25 kg) (Table 4.2). Hockey (63.69 kg), soccer (63.68 kg) and tennis (62.36 kg) had similar mean values for age.

Similarly, Figure 4.2 suggests that the BMI of the athletes is similar for hockey, soccer and tennis. However, running has notably lower values for BMI than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartile of the other distributions (Table 4.2) Netball (23.20 kg.m^{-2}) had the highest mean value for BMI and running the lowest (20.09 kg.m^{-2}) (Table 4.2). Hockey (22.78 kg.m^{-2}), soccer (22.49 kg.m^{-2}) and tennis (22.59 kg.m^{-2}) had similar mean values for BMI.

4.2.3 Comparison of sports with regard to anthropometric characteristics

Table 4.3 shows that the difference for overall sports is statistically significant with respect to four of the five anthropometric characteristics, but differences in height are not statistically significant between sports. However, the effect size of sport is negligible for height (ω in the range 0.00-0.10) (Schober *et al.*, 2018:1765) and small for age, weight and BMI (ω in the range 0.10-0.39) (Schober *et al.*, 2018:1765), whilst the effect size of sport for fat percentage is moderately large (ω in the range 0.40-0.69) (Schober *et al.*, 2018:1765).

Table 4.3: Overall comparison[a] of sports with regard to anthropometric characteristics

Dependent Variable	F-statistic (df=4, 78)	P-value	Effect Size	
			Partial ω^2	$\omega = \sqrt{\omega^2}$
Age	4.35	0.0032*	0.1389	0.37
Height	1.01	0.4067	0.0006	0.02
Weight	2.99	0.0238	0.0874	0.30
Fat Percentage	8.21	<0.0001*	0.2580	0.51
BMI	4.67	0.0020*	0.1504	0.39

[a]F-statistic, P-value and effect size statistic from one-way analysis of variance (ANOVA) model with sport as fixed effect.

Table 4.4 displays the mean values of the five characteristics of anthropometric characteristics for each sport, together with a summary of the pairwise statistical comparisons (A, B, or C) of the sports with regard to the five characteristics of anthropometric characteristics; the detailed P-values associated with these pairwise comparison are presented in Table 4.5.

Table 4.4: Mean values of characteristics of anthropometric characteristics and summary display of pairwise comparisons of sports (Table 4.4 continues on next page)

Dependent Variable	Sport	Mean[b]	Pairwise comparison of sports[c]	
Age	**Soccer**	21.47	A	
	Tennis	20.45	A	B
	Hockey	20.42		B

	Netball	19.94		B	
	Runner	19.67		B	
Height	**Runner**	1.70	A		
	Netball	1.69	A		
	Soccer	1.68	A		
	Hockey	1.67	A		
	Tennis	1.66	A		
Weight	**Netball**	66.40	A		
	Hockey	63.69	A		
	Soccer	63.68	A		
	Tennis	62.36	A	B	
	Runner	58.27		B	
Fat Percentage	**Netball**	24.09	A		
	Soccer	22.57	A	B	
	Hockey	22.37	A	B	
	Tennis	21.87		B	
	Runner	18.47			C
BMI	**Netball**	23.20	A		
	Hockey	22.78	A		
	Tennis	22.59	A		
	Soccer	22.49	A		
	Runner	20.09		B	

[b]Mean estimates from one-way analysis of variance (ANOVA) model with sport as fixed effect.

[c]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter show a statistically significant difference.

Table 4.5: Pairwise P-values comparing sports with regard to anthropometric characteristics (Table 4.5 continues on next page)

Dependent Variable	Sport	Hockey	Netball	Runner	Soccer	Tennis
Age	**Hockey**		0.2696	0.0919	0.0149*	0.9381
	Netball	0.2696		0.5741	0.0015*	0.3259
	Runner	0.0919	0.5741		0.0003*	0.1412
	Soccer	0.0149*	0.0015*	0.0003*		0.0528
	Tennis	0.9381	0.3259	0.1412	0.0528	
Height	**Hockey**		0.4051	0.1371	0.6477	0.5486
	Netball	0.4051		0.5344	0.7212	0.2151
	Runner	0.1371	0.5344		0.3276	0.0760
	Soccer	0.6477	0.7212	0.3276		0.3488
	Tennis	0.5486	0.2151	0.0760	0.3488	
Weight	**Hockey**		0.2188	0.0168*	0.9965	0.5915
	Netball	0.2188		0.0012*	0.2525	0.1319
	Runner	0.0168*	0.0012*		0.0262*	0.1295
	Soccer	0.9965	0.2525	0.0262*		0.6160
	Tennis	0.5915	0.1319	0.1295	0.6160	
Fat Percentage	**Hockey**		0.0636	<0.0001*	0.9136	0.6285
	Netball	0.0636		<0.0001*	0.1040	0.0487*
	Runner	<0.0001*	<0.0001*		0.0002*	0.0034*
	Soccer	0.9136	0.1040	0.0002*		0.5865
	Tennis	0.6285	0.0487*	0.0034*	0.5865	
BMI	**Hockey**		0.5657	0.0005*	0.6835	0.8146
	Netball	0.5657		0.0002*	0.3672	0.4897

Runner	0.0005*	0.0002*		0.0033*	0.0061*
Soccer	0.6835	0.3672	0.0033*		0.9096
Tennis	0.8146	0.4897	0.0061*	0.9096	

Table 4.4 shows that soccer and tennis do not differ from each other in a statistically significant way with regard to age, but for this variable soccer does show a statistically significant difference from hockey, netball and running, respectively (see pairwise P-values in Table 4.5). Thus, the mean age of soccer players is significantly higher than that of hockey and netball players, and of runners. With regard to height in running, netball, soccer, hockey and tennis, there is no statistically significant difference (see pairwise P-values in Table 4.5). Table 4.4 also shows that netball, hockey, soccer and tennis do not show statistically significant difference from each other with regard to weight (see pairwise P-values in Table 4.5). Similarly, tennis and running do not show statistically significant differences from each other, but running shows statistically significant differences from netball, hockey and soccer, respectively. Thus, the weight of runners is significantly lower than that of netball, hockey and soccer players. With regard to fat percentage, netball, soccer and hockey do not show statistically significant differences from each other (see pairwise P-values in Table 4.5), and soccer, hockey and tennis do not show statistically significant differences from each other (see pairwise P-values in Table 4.5). Running, however, shows statistically significant differences from this group of sports (netball, soccer, hockey and tennis; see pairwise P-values in Table 4.5), having the lowest mean value for fat percentage. Lastly, Table 4.4 shows that netball, hockey, tennis and soccer do not show statistically significant differences from each other with regard to BMI, but for this variable, running shows a statistically significant difference from this group of sports (netball, hockey, tennis and soccer; see pairwise P-values in Table 4.5). Thus, the mean BMI anthropometric characteristic of runners is significantly lower than that of the other four sports.

4.3 CORE STRENGTH

4.3.1 Descriptive statistics for core strength

Table 4.6 presents the descriptive statistics for the three characteristics of core strength, overall and by the type of sport. Similarly, Figures 4.3 – 4.5 present box plots of the IBE, LF and AF characteristics of core strength and core endurance by type of sport.

Table 4.6: Descriptive statistics for core strength: Overall and by type of sport

		All Sports	Hockey	Netball	Runner	Soccer	Tennis
IBE [N]	**N**	**83**	**24**	**16**	**15**	**17**	**11**
	Mean	1002.47	1056.58	1036.75	1024.07	1017.00	782.64
	Std	206.31	208.46	209.89	191.12	205.48	34.03
	Min	687.00	750.00	687.00	757.00	748.00	745.00
	Q1	792.00	906.00	878.00	791.00	869.00	750.00
	Median	965.00	1016.00	1062.00	995.00	985.00	778.00
	Q3	1148.00	1248.00	1114.50	1201.00	1135.00	810.00
	Max	1517.00	1422.00	1517.00	1303.00	1517.00	540.00
LF [N]	**Mean**	799.04	857.83	799.44	772.53	824.41	667.09
	Std	141.26	149.97	113.04	153.61	135.34	28.21
	Min	565.00	586.00	639.00	565.00	625.00	625.00
	Q1	680.00	730.00	719.50	602.00	749.00	640.00
	Median	775.00	911.50	767.00	803.00	789.00	663.00
	Q3	925.00	985.00	873.50	905.00	952.00	696.00
	Max	1082.00	1082.00	1018.00	984.00	1018.00	701.00
AF [N]	**Mean**	897.22	958.25	905.56	859.00	941.47	735.64
	Std	162.34	175.43	130.37	157.48	160.61	23.18
	Min	646.00	646.00	684.00	687.00	695.00	690.00
	Q1	745.00	821.00	835.00	710.00	816.00	737.00
	Median	881.00	996.00	887.50	840.00	958.00	739.00

Q3	1009.00	1081.50	965.00	960.00	1029.00	748.00
Max	1300.00	1274.00	1300.00	1188.00	1214.00	769.00

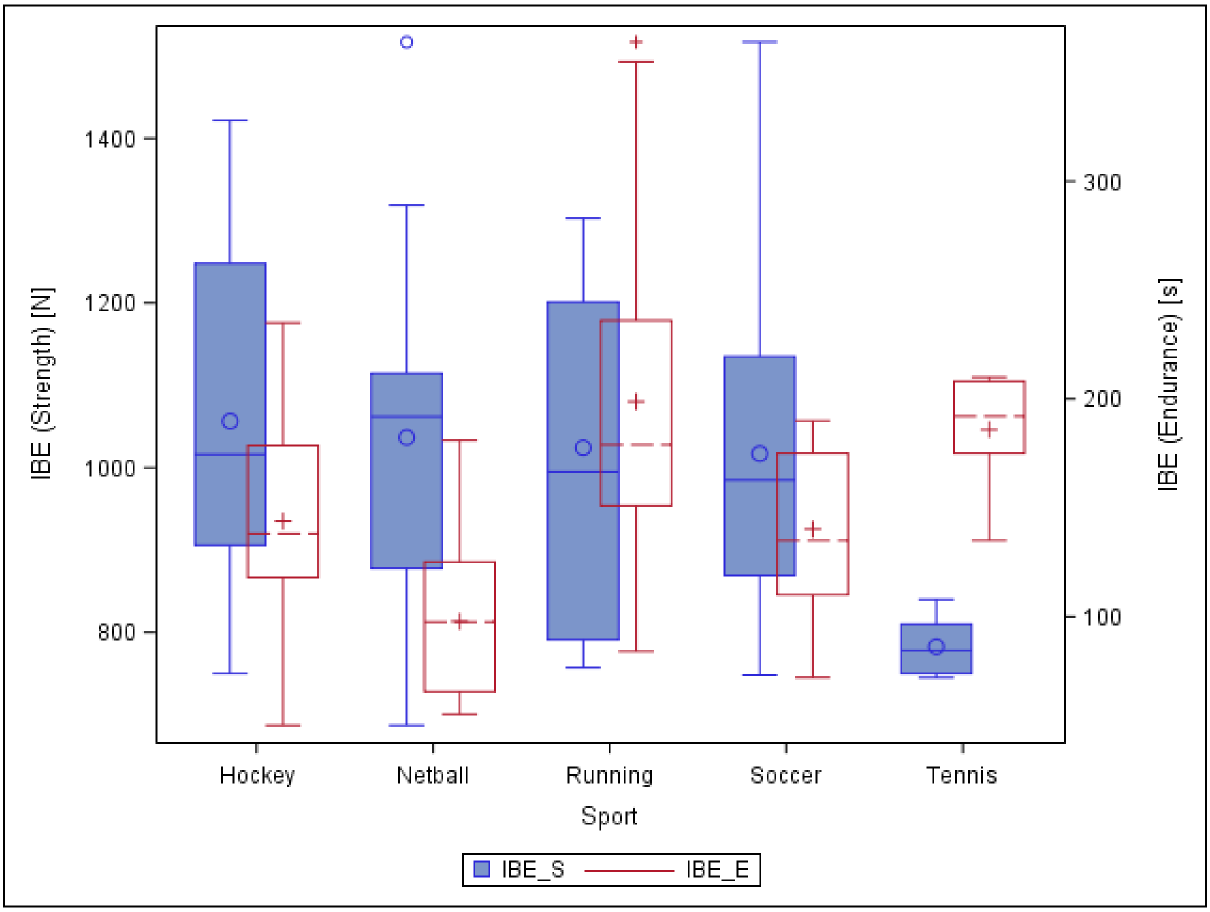

Figure 4.3: Box plot: IBE characteristic of core strength and core endurance by type of sport

Figure 4.3 suggests that IBE (Strength) is similar for hockey, netball, running and soccer. However, tennis has notably lower values of IBE (Strength) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.6). Hockey (1 056.58N) had the highest mean value for IBE (Strength) and tennis the lowest (782.64N) (Table 4.6). Netball (1 036.75N), running (1 024.07N) and soccer (1 017.00N) had similar mean values for IBE (Strength).

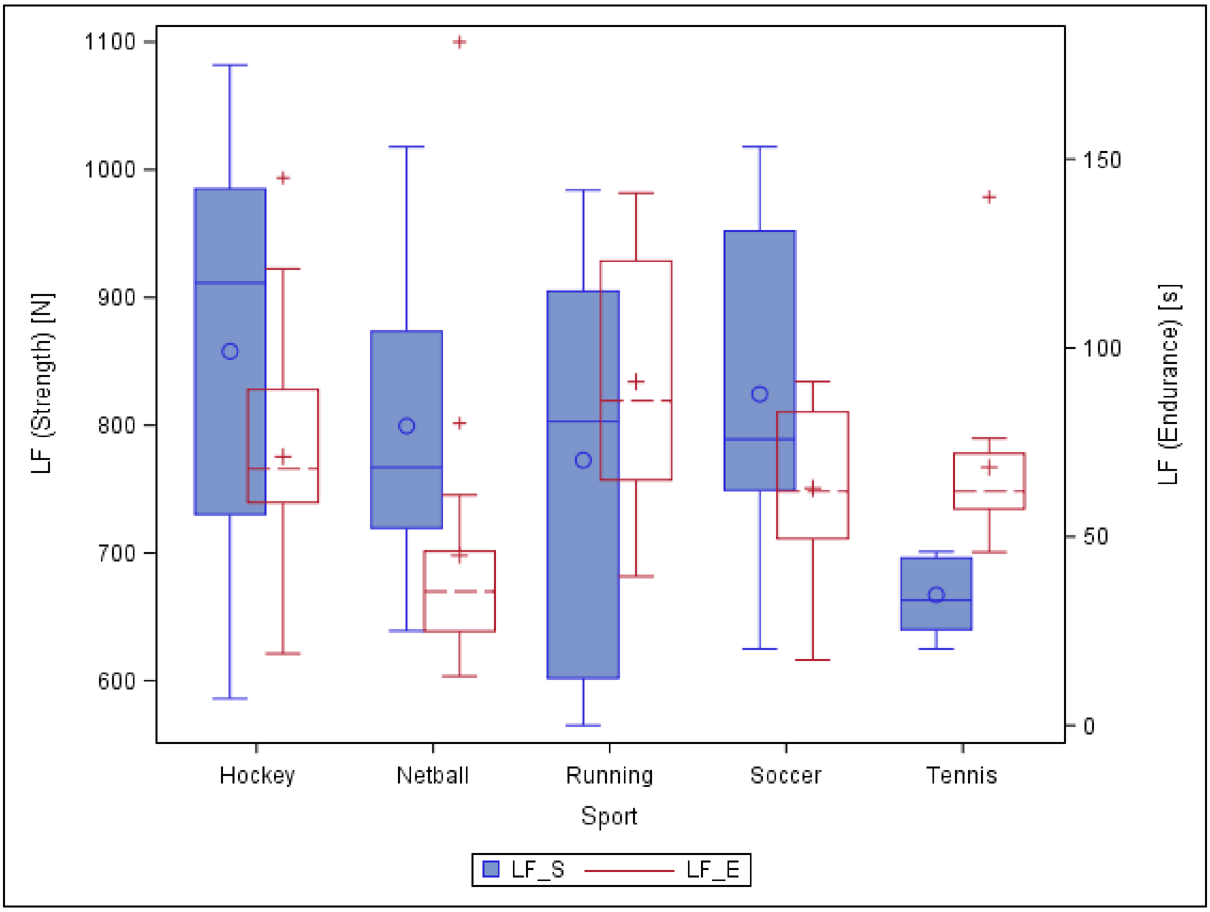

Figure 4.4: Box plot: LF characteristic of core strength and core endurance by type of sport

Figure 4.4 suggests that LF (Strength) is similar for netball, running and soccer. However, tennis has notably lower values of LF (Strength) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.6). Hockey (857.83N) had the highest mean value for LF (Strength) and tennis the lowest (667.09N) (Table 4.6). Netball (799.44N), running (772.53N) and soccer (824.41N) had similar mean values for LF (Strength).

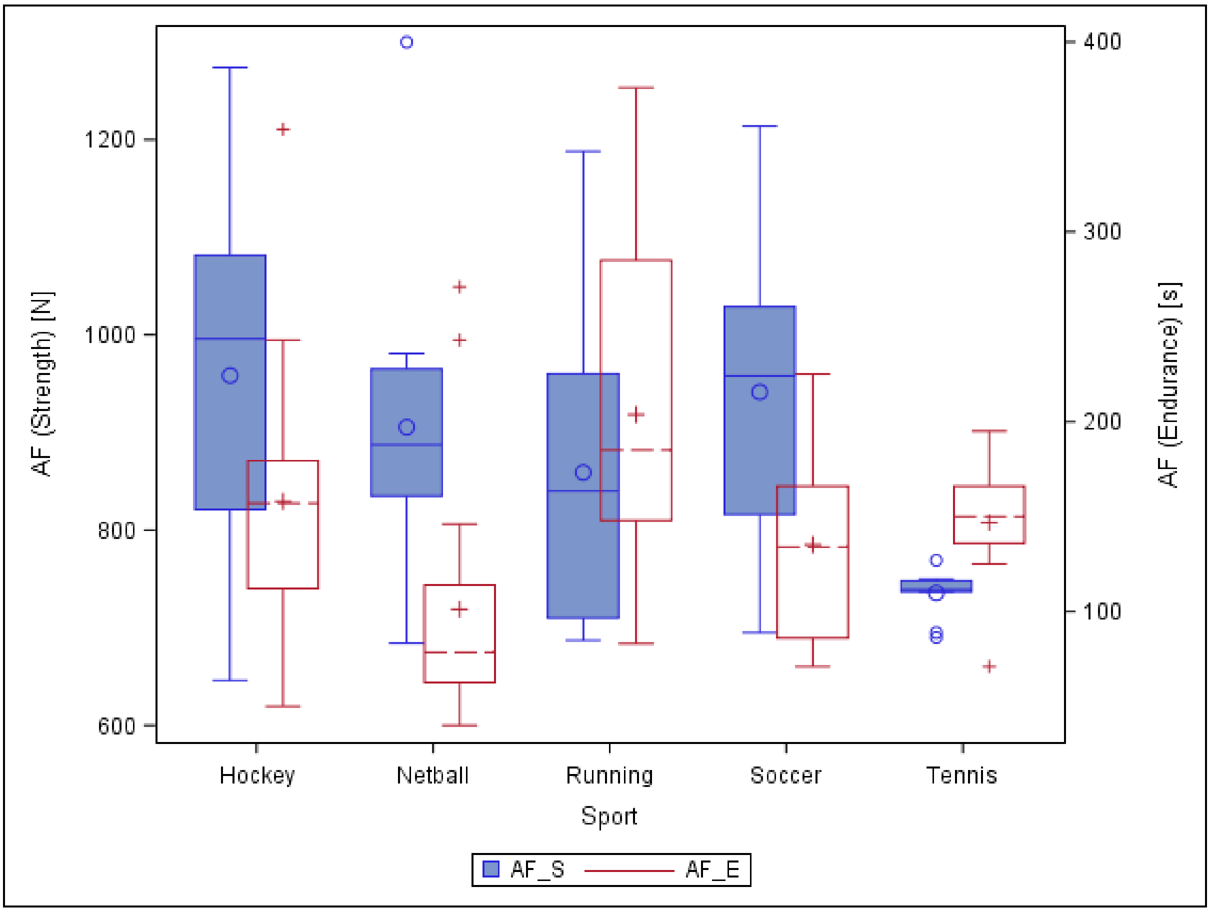

Figure 4.5: Box plot: AF characteristic of core strength and core endurance by type of sport

Figure 4.5 suggests that AF (Strength) is similar for netball, running and soccer. However, tennis has notably lower values of AF (Strength) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.6). Hockey (958.25N) had the highest mean value for AF (Strength) and tennis the lowest (735.64N) (Table 4.6). Netball (905.56N), running (859.00N) and soccer (941.47N) had similar mean values for AF (Strength).

4.3.2 Comparison of sports with regard to core strength

Table 4.7 shows that, overall, sports show statistically significant differences with respect to all three characteristics of core strength. However, the effect size of sport is small for IBE and LF (ω in the range 0.10-0.39) (Schober *et al.*, 2018:1765), whilst the effect size of sport for AF is moderately large (ω in the range 0.40-0.69) (Schober *et al.*, 2018:1765).

Table 4.7: Overall comparison[a] of sports with regard to core strength

Dependent Variable	F-statistic (df=4, 78)	P-value	Effect Size	
			Partial $\boldsymbol{\omega^2}$	$\omega = \sqrt{\boldsymbol{\omega^2}}$
IBE	4.31	0.0034*	0.1374	0.37
LF	4.31	0.0034*	0.1374	0.37
AF	4.89	0.0014*	0.1577	0.40

[a]F-statistic, P-value and effect size statistic from one-way analysis of variance (ANOVA) model with sport as fixed effect.

Table 4.8 displays the mean values of the three characteristics of core strength for each sport, together with a summary of the pairwise statistical comparisons of the sports with regard to the three characteristics of core strength; the detailed P-values associated with these pairwise comparisons are presented in Table 4.9.

Table 4.8: Mean values of characteristics of core strength and summary display of pairwise comparisons of sports (Table 4.8 continues on next page)

Dependent Variable	Sport	Mean[b]	Pairwise comparison of sports[c]	
IBE	**Hockey**	1056.58	A	
	Netball	1036.75	A	
	Runner	1024.07	A	
	Soccer	1017.00	A	
	Tennis	782.64		B
LF	**Hockey**	857.833	A	
	Soccer	824.412	A	
	Netball	799.438	A	
	Runner	772.533	A	
	Tennis	667.091		B
AF	**Hockey**	958.250	A	
	Soccer	941.471		B

Netball	905.563	A	B	
Runner	859.000	A	B	
Tennis	735.636			C

[b]Mean estimates from one-way analysis of variance (ANOVA) model with sport as fixed effect.

[c]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter show statistically significant differences.

Table 4.9: Pairwise P-values comparing sports with regard to core strength

Dependent Variable	**Sport**	**Hockey**	**Netball**	**Runner**	**Soccer**	**Tennis**
IBE	**Hockey**		0.7491	0.6073	0.5162	0.0002*
	Netball	0.7491		0.8542	0.7679	0.0011*
	Runner	0.6073	0.8542		0.9173	0.0021*
	Soccer	0.5162	0.7679	0.9173		0.0022*
	Tennis	0.0002*	0.0011*	0.0021*	0.0022*	
LF	**Hockey**		0.1715	0.0516	0.4237	0.0001*
	Netball	0.1715		0.5696	0.5860	0.0118*
	Runner	0.0516	0.5696		0.2674	0.0462*
	Soccer	0.4237	0.5860	0.2674		0.0027*
	Tennis	0.0001*	0.0118*	0.0462*	0.0027*	
AF	**Hockey**		0.2761	0.0462*	0.7231	<0.0001*
	Netball	0.2761		0.3867	0.4906	0.0046*
	Runner	0.0462*	0.3867		0.1218	0.0401*
	Soccer	0.7231	0.4906	0.1218		0.0006*
	Tennis	<0.0001*	0.0046*	0.0401*	0.0006*	

The display in Table 4.8 shows that hockey, netball, running and soccer do not show statistically significant differences from each other with regard to the IBE and LF characteristics of core strength, but for these two variables, tennis shows statistically significant differences from this group of sports (hockey, netball, running and soccer; see pairwise P-values in Table 4.9). Thus, the IBE and LF values of core strength are significantly lower for tennis than for the other four sports. With regard to the AF characteristic of core strength, hockey, soccer and netball did not show statistically significant differences from each other. Similarly, soccer, netball and running did not show statistically significant differences from each other, but hockey did show a statistically significant difference from running. As before, tennis showed a statistically significant difference from hockey, soccer, netball and running (see pairwise P-values in Table 4.9), having the lowest mean value for AF.

4.4 CORE ENDURANCE

4.4.1 Descriptive statistics for core endurance

Table 4.10 shows the descriptive statistics with respect to the three characteristics of core endurance, overall and by the type of sport.

Table 4.10: Descriptive statistics for core endurance: Overall and by type of sport

		All Sports	**Hockey**	**Netball**	**Runner**	**Soccer**	**Tennis**
IBE [s]	**N**	**83**	**24**	**16**	**15**	**17**	**11**
	Mean	149.74	143.92	97.75	198.80	140.18	185.91
	Std	58.42	47.95	36.36	77.95	36.03	22.73
	Min	50.00	50.00	55.06	84.00	72.00	135.00
	Q1	114.00	118.00	65.50	151.00	110.00	175.00
	Median	150.00	138.00	97.50	179.00	135.00	192.00
	Q3	180.00	178.50	125.00	236.00	175.00	208.00
	Max	364.00	235.00	181.00	364.00	190.00	210.00
LF [s]	**Mean**	67.62	71.18	44.99	90.97	62.81	68.35
	Std	33.07	29.20	39.92	33.29	20.94	25.62
	Min	13.00	19.00	13.00	37.47	17.28	45.90
	Q1	44.00	59.00	24.95	65.00	49.50	57.37
	Median	62.00	68.00	35.50	86.00	62.00	62.00

	Q3	85.00	89.00	46.10	123.00	83.00	72.00
	Max	181.00	145.00	181.00	141.00	91.00	140.00
AF [s]	**Mean**	149.16	157.96	101.26	203.67	135.24	146.82
	Std	70.09	63.23	66.92	88.95	47.64	31.83
	Min	40.00	50.00	40.00	83.00	71.00	71.00
	Q1	89.00	112.00	62.44	148.00	86.00	136.00
	Median	148.00	157.00	78.50	185.00	134.00	150.00
	Q3	178.00	179.50	114.00	285.00	166.00	166.00
	Max	376.00	354.00	271.00	376.00	225.00	195.00

Figure 4.3 suggests that IBE (Endurance) is similar for hockey and soccer. However, netball has notably lower values of IBE (Endurance) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.10). Running (198.80 s) had the highest mean value and netball the lowest (97.75 s) (Table 4.10). Hockey (143.92 s) and tennis (185.91 s) had similar mean values for IBE (Endurance), except for soccer (140.18 s) where the mean value differs from the other sports.

Similarly, Figure 4.4 suggests that LF (Endurance) is similar for hockey, soccer and tennis. However, netball has notably lower values of LF (Endurance) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.10). Running (90.97 s) had the highest mean value for LF (Endurance) and netball the lowest (44.99 s) (Table 4.10). Hockey (71.18 s), soccer (62.81 s) and tennis (68.35 s) had similar mean values for LF (Endurance).

Similarly, Figure 4.3 suggests that AF (Endurance) is similar for hockey, soccer and tennis. However, netball has notably lower values of AF (Endurance) than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartiles of the distributions for the other sports (Table 4.10). Running (203.67 s) had the highest mean value for AF (Endurance) and netball the lowest (101.26 s) (Table 4.10). Hockey (157.96 s), soccer (135.24 s) and tennis (146.82 s) had similar mean values for AF (Endurance).

4.4.2 Comparison of sports with regard to core endurance

Table 4.11 shows that, overall, sports show statistically significant differences with respect to all three characteristics of core endurance. However, the effect size of sport is moderately large for IBE and AF (ω in the range 0.40-0.69) (Schober *et al*., 2018:1765), whilst the effect size of sport for LF is small (ω in the range 0.10-0.39) (Schober *et al*., 2018:1765).

Table 4.11: Overall comparison[a] of sports with regard to core endurance

Dependent Variable	**F-statistic (df=4, 78)**	**P-value**	**Effect Size**	
			Partial $\boldsymbol{\omega^2}$	$\omega = \sqrt{\boldsymbol{\omega^2}}$
IBE	10.20	<0.0001*	0.3072	0.55
LF	4.58	0.0022*	0.1473	0.38
AF	5.33	0.0008*	0.1727	0.42

[a]F-statistic, P-value and effect size statistic from one-way analysis of variance (ANOVA) model with sport as fixed effect.

Table 4.12 displays the mean values of the three characteristics of core endurance for each sport, together with a summary of the pairwise statistical comparisons of the sports with regard to the three characteristics of core endurance; the detailed P-values associated with these pairwise comparisons are presented in Table 4.13.

Table 4.12: Mean values of characteristics of core endurance and summary display of pairwise comparisons of sports (Table 4.12 continues on next page)

Dependent Variable	**Sport**	**Mean[b]**	**Pairwise comparison of sports[c]**		
IBE	**Runner**	198.80	A		
	Tennis	185.91	A		
	Hockey	143.92		B	
	Soccer	140.18		B	
	Netball	97.75			C
LF	**Runner**	90.97	A		
	Hockey	71.18	A	B	

	Tennis	68.35	A	B	C
	Soccer	62.81		B	C
	Netball	44.99			C
AF	**Runner**	203.67	A		
	Hockey	157.96		B	
	Tennis	146.82		B	C
	Soccer	135.24		B	C
	Netball	101.26			C

[b]Mean estimates from one-way analysis of variance (ANOVA) model with sport as fixed effect.

[c]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter show statistically significant differences.

Table 4.13: Pairwise P-values comparing sports with regard to core endurance (Table 4.13 continues on next page)

Dependent Variable	Sport	Hockey	Netball	Runner	Soccer	Tennis
IBE	**Hockey**		0.0042*	0.0010*	0.8086	0.0199*
	Netball	0.0042*		<0.0001*	0.0142*	<0.0001*
	Runner	0.0010*	<0.0001*		0.0010*	0.5054
	Soccer	0.8086	0.0142*	0.0010*		0.0172*
	Tennis	0.0199*	<0.0001*	0.5054	0.0172*	
LF	**Hockey**		0.0095*	0.0524	0.3893	0.7996
	Netball	0.0095*		<0.0001*	0.0976	0.0542
	Runner	0.0524	<0.0001*		0.0110*	0.0656
	Soccer	0.3893	0.0976	0.0110*		0.6400
	Tennis	0.7996	0.0542	0.0656	0.6500	
AF	**Hockey**		0.0072*	0.0322*	0.2638	0.6323
	Netball	0.0072*		<0.0001*	0.1297	0.0716
	Runner	0.0322*	<0.0001*		0.0033*	0.0274*

Soccer	0.2638	0.1297	0.0033*		0.6397
Tennis	0.6323	0.0716	0.0274*	0.6397	

The display in Table 4.12 shows that running and tennis do not show a statistically significant difference from each other with regard to the IBE characteristic of core endurance, but for this variable hockey, soccer and netball show a statistically significant difference from running and tennis (see pairwise P-values in Table 4.13). Similarly, hockey and soccer do not show a statistically significant difference from each other with regard to the IBE characteristic of core endurance, but for this variable, running, tennis and netball show statistically significant differences from hockey and soccer (see pairwise P-values in Table 4.13). Thus, netball shows a statistically significant difference from this group of sports (hockey, running, soccer and tennis) and the IBE values of core endurance are significantly lower for netball than for the other four sports. With regard to the LF characteristic of core endurance, running, hockey and tennis do not show statistically significant differences from each other. Similarly, hockey, tennis and soccer do not show statistically significant differences from each other, as well as tennis, soccer and netball which do not show a statistically significant difference from each other, but running does show a statistically significant difference from soccer and netball and hockey shows a statistically significant difference from netball. As before, netball has the lowest LF mean value for core endurance (see pairwise P-values in Table 4.13). The display in Table 4.12 also shows that hockey, tennis and soccer do not show statistically significant differences from each other with regard to the AF characteristic of core endurance, and for this same variable, tennis, soccer and netball do not show a statistically significant difference from each other (see pairwise P-values in Table 4.13). However, running, hockey and netball show a statistically significant difference from each other, and running shows a statistically significant difference from this group of sports (hockey, tennis, soccer and netball; see pairwise P-values in Table 4.13), having the highest mean value for AF.

4.5 CORE MOTOR CONTROL

4.5.1 Descriptive statistics for core motor control

Table 4.14 shows the descriptive statistics with respect to core motor control, overall and by the type of sport.

Table 4.14: Descriptive statistics for core motor control: Overall and by type of sport

Team	Statistic	NMC					Total
		1	**2**	**3**	**4**	**5**	
All sports	Frequency	13	17	31	21	1	83
	Percent	15.66	20.48	37.35	25.30	1.20	
Hockey	Frequency	3	3	10	8	0	24
	Percent	12.50	12.50	41.67	33.33	0.00	
Netball	Frequency	9	5	1	1	0	16
	Percent	56.25	31.25	6.25	6.25	0.00	
Runner	Frequency	0	2	6	6	1	15
	Percent	0.00	13.33	40.00	40.00	6.67	
Soccer	Frequency	1	6	7	3	0	17
	Percent	5.88	35.29	41.18	17.65	0.00	
Tennis	Frequency	0	1	7	3	0	11
	Percent	0.00	9.09	63.64	27.27	0.00	

4.5.2 Comparison of sports with regard to core motor control

Table 4.15 illustrates that overall sports show statistically significant differences with respect to core motor control. However, the effect size of sport is moderately large for NMC (ω in the range 0.40-0.69) (Schober *et al.*, 2018:1765).

Table 4.15: Overall comparison[a] of sports with regard to core motor control

Dependent Variable	F-statistic (df=4, 78)	P-value	Effect Size	
			Partial ω^2	$\omega = \sqrt{\omega^2}$
NMC	9.74	<0.0001*	0.2964	0.54

[a]F-statistic, P-value and effect size statistic from one-way analysis of variance (ANOVA) model with sport as fixed effect.

Table 4.16 displays the mean values of core motor control for each sport, together with a summary of the pairwise statistical comparisons of the sports with regard to core motor control; the detailed P-values associated with these pairwise comparisons are presented in Table 4.27.

Table 4.16: Mean values of core motor control and summary display of pairwise comparisons of sports

Dependent Variable	Sport	Mean[b]	Pairwise comparison of sports[c]		
NMC	**Runner**	3.40	A		
	Tennis	3.18	A	B	
	Hockey	2.96	A	B	
	Soccer	2.71		B	
	Netball	1.63			C

[b]Mean estimates from one-way analysis of variance (ANOVA) model with sport as fixed effect.

[c]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter show statistically significant differences.

Table 4.17: Pairwise P-values comparing sports with regard to core motor control

Dependent Variable	Sport	Hockey	Netball	Runner	Soccer	Tennis
NMC	**Hockey**		<0.0001*	0.1284	0.3646	0.4842
	Netball	<0.0001*		<0.0001*	0.0006*	<0.0001*
	Runner	0.1284	<0.0001*		0.0277*	0.5309
	Soccer	0.3646	0.0006*	0.0277*		0.1629
	Tennis	0.4842	<0.0001*	0.5309	0.1629	

Table 4.16 shows that running, tennis and hockey do not show statistically significant differences from each other with regard to core motor control, and tennis, hockey and soccer do not show statistically significant differences from each other, but for this variable, running, soccer and netball show statistically significant differences from each other and netball shows a statistically significant difference from this group of sports (running, tennis, hockey and soccer; see pairwise P-values in Table 4.17).

4.6 ATHLETIC PERFORMANCE

4.6.1 Descriptive statistics for athletic performance

Table 4.18 shows the descriptive statistics with respect to the four characteristics of athletic performance, overall and by the type of sport. Similarly, Figures 4.3 – 4.5 present box plots of the IBE, LF and AF characteristics of core strength and core endurance by type of sport.

Table 4.18: Descriptive statistics for athletic performance variables: Overall and by type of sport (Table 4.18 continues on next page)

		All Sports	**Hockey**	**Netball**	**Runner**	**Soccer**	**Tennis**
40 m Sprint [s]	**N**	**83**	**24**	**16**	**15**	**17**	**11**
	Mean	6.40	6.35	6.58	6.10	6.47	6.54
	Std	0.40	0.43	0.36	0.28	0.41	0.29
	Min	5.73	5.96	6.08	5.73	5.96	6.08
	Q1	6.08	6.09	6.30	5.93	6.21	6.44
	Median	6.30	6.23	6.47	6.05	6.29	6.52
	Q3	6.59	6.42	6.85	6.23	6.67	6.67
	Max	7.87	7.87	7.23	6.89	7.23	7.13
T-Test [s]	**Mean**	12.70	12.29	12.73	12.24	12.76	13.42
	Std	0.81	0.73	0.89	0.77	0.79	0.36
	Min	11.06	11.24	11.06	11.35	11.24	13.05

	Q1	12.06	11.69	12.08	12.22	12.06	13.06
	Median	12.68	12.13	12.61	12.59	12.54	13.38
	Q3	13.34	12.90	13.41	12.90	13.42	13.82
	Max	14.35	13.95	14.25	14.35	14.05	13.95
Vertical Jump [cm]	**Mean**	43.49	45.47	44.56	45.67	41.88	37.00
	Std	4.92	3.81	4.49	5.38	3.26	2.72
	Min	30.00	37.00	38.00	34.00	36.00	30.00
	Q1	39.00	42.00	41.00	44.00	39.00	36.00
	Median	44.00	45.50	44.50	45.00	41.00	37.00
	Q3	47.00	48.50	47.50	50.00	45.00	39.00
	Max	56.00	51.00	55.00	56.00	48.00	40.00
Medicine Ball Chest Throw [m]	**Mean**	4.32	4.45	4.35	4.44	4.27	3.88
	Std	0.48	0.49	0.44	0.55	0.38	0.35
	Min	3.48	3.48	3.80	3.80	3.48	3.48
	Q1	4.00	4.20	4.10	3.90	4.10	3.60
	Median	4.30	4.50	4.25	4.50	4.20	3.70
	Q3	4.60	4.80	4.39	4.70	4.50	4.20
	Max	5.95	5.50	5.60	5.95	4.90	4.50

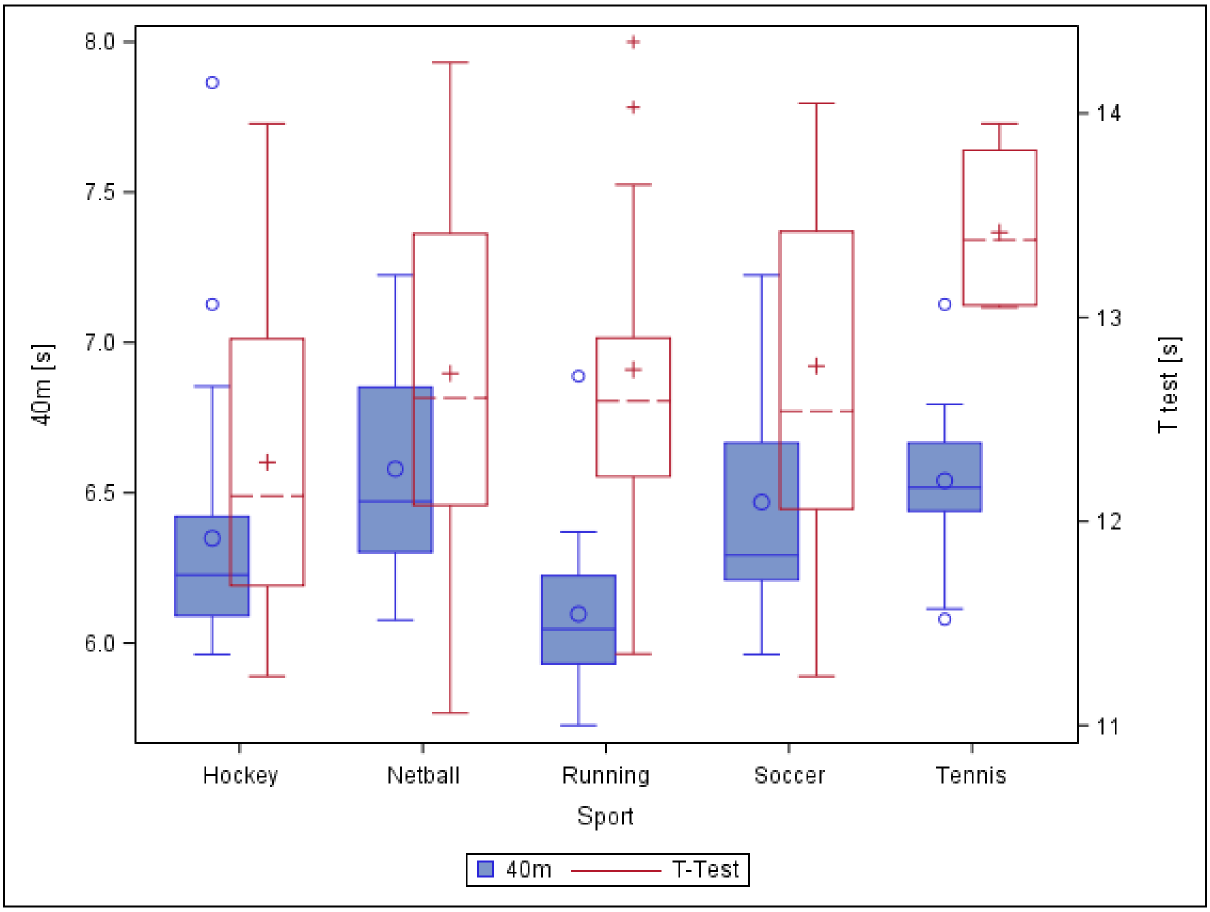

Figure 4.6: Box plot: 40 m sprint and T-Test characteristics of athletic performance by type of sport

Figure 4.6 suggests that the 40 m sprint is similar for hockey, soccer and tennis. However, running has notably lower values of the 40 m sprint than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartile of the distributions for the other sports (Table 4.18). Netball (6.58 s) had the highest mean value for the 40 m sprint and running the lowest (6.10 s) (Table 4.18). Hockey (6.35 s), soccer (6.47 s) and tennis (6.54 s) had similar mean values for the 40 m sprint.

Figure 4.6 also suggests that the T-Test is similar for hockey and running and likewise for netball and soccer. However, hockey has notably lower values of the T-Test than the other sports, with the upper quartile of the distribution being lower than the lower quartile of the distribution for tennis and similar to the centre of the distributions for the other sports (Table 4.18). Tennis (13.42 s) had the highest mean value for the T-Test and hockey the lowest (12.29 s) (Table 4.18). Running (12.24 s) had a similar mean value as hockey and netball (12.73 s) and soccer (12.76 s) had similar mean values for the T-Test.

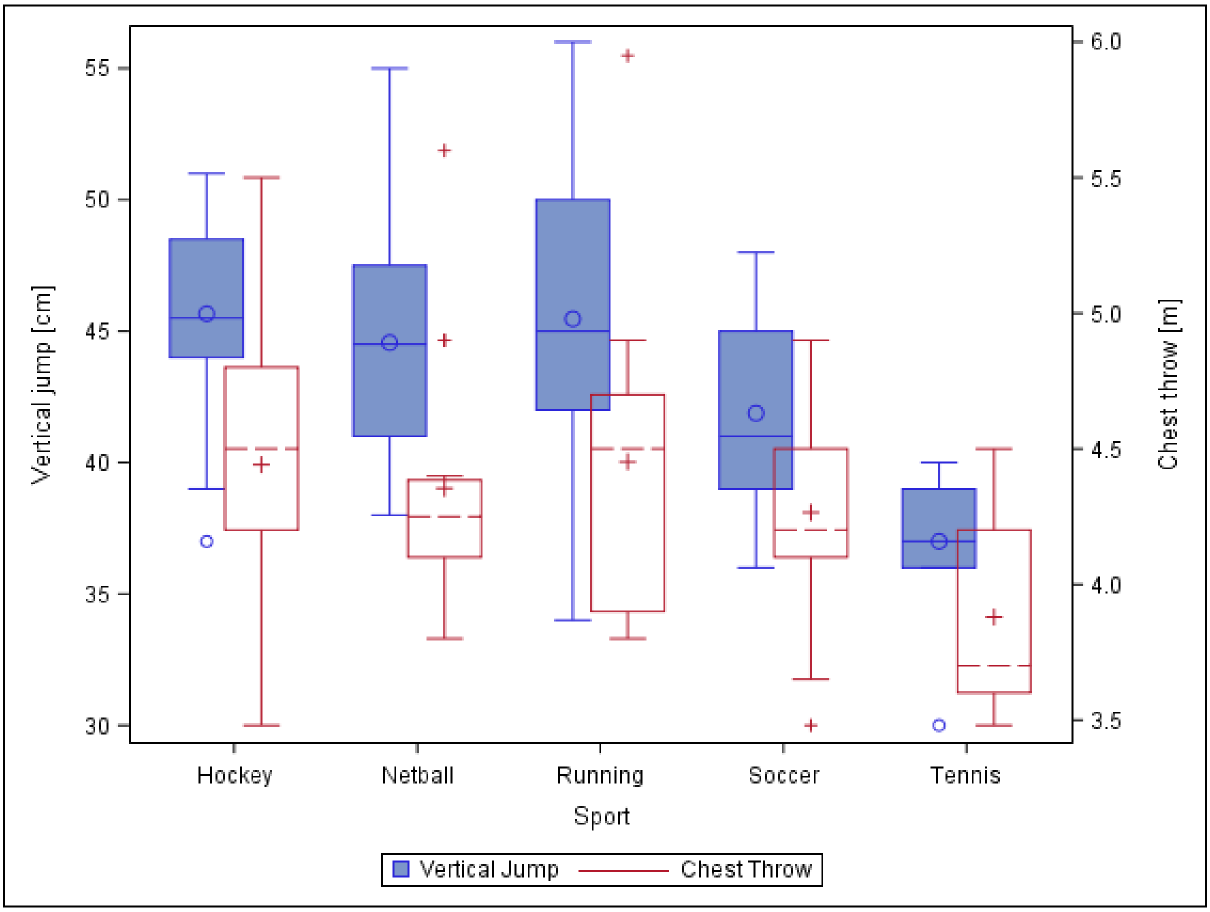

Figure 4.7: Box plot: Vertical jump and medicine ball chest throw characteristics of athletic performance by type of sport

Figure 4.7 suggests that the vertical jump is similar for hockey, netball and soccer. However, tennis has notably lower values of the vertical jump than the other sports, with the upper quartile of the distribution being lower than or similar to the lower quartile of the distributions for the other sports (Table 4.18). Running (45.67 m) had the highest mean value for the vertical jump and tennis the lowest (37.00 m) (Table 4.18). Hockey (45.47 m), netball (44.56 m) and soccer (41.88 m) had similar mean values for the vertical jump.

Figure 4.7 also suggests that the medicine ball chest throw is similar for hockey and running and likewise for netball and soccer. However, tennis has notably lower values of the medicine ball chest throw than the other sports, with the upper quartile of the distribution being similar to the lower quartiles of the distributions for the other sports (Table 4.18). Hockey (4.45 m) had the highest mean value for the medicine ball chest throw and tennis the lowest (3.88 m) (Table 4.18). Running (4.44 m) had a similar mean value to hockey and netball (4.35 m) and soccer (4.27 m) had similar mean values for the medicine ball chest throw.

4.6.2 Comparison of sports with regard to athletic performance

Table 4.19 illustrates that, overall, sports showed a statistically significant difference with respect to all four athletic performance characteristics. However, the effect size of sport is small for the 40 m sprint, T-test and medicine ball chest throw (ω in the range 0.10-0.39) (Schober *et al.*, 2018:1765), whilst the effect size of sport for the vertical jump is moderately large (ω in the range 0.40-0.69) (Schober *et al.*, 2018:1765).

Table 4.19: Overall comparison[a] of sports with regard to athletic performance

Dependent Variable	F-statistic (df=4, 78)	P-value	Effect Size	
			Partial ω^2	$\omega = \sqrt{\omega^2}$
40 m sprint	4.01	0.0052*	0.1265	0.36
T-Test	4.35	0.0031*	0.1390	0.37
Vertical Jump	10.59	<0.0001*	0.3162	0.56
Medicine Ball Chest Throw	3.38	0.0133*	0.1029	0.32

[a]F-statistic, P-value and effect size statistic from one-way analysis of variance (ANOVA) model with sport as fixed effect.

Table 4.20 displays the mean values of the four characteristics of athletic performance for each sport, together with a summary of the pairwise statistical comparisons of the sports with regard to the four characteristics of athletic performance; the detailed P-values associated with these pairwise comparisons are presented in Table 4.21.

Table 4.20: Mean values of characteristics of athletic performance and summary display of pairwise comparisons of sports (Table 4.20 continues on next page)

Dependent Variable	Sport	Mean[b]	Pairwise comparison of sports[c]	
40 m sprint	**Netball**	6.58	A	
	Tennis	6.54	A	
	Soccer	6.47	A	
	Hockey	6.35	A	
	Runner	6.10		B

T-Test	**Tennis**	13.42	A		
	Soccer	12.76		B	
	Runner	12.74		B	
	Netball	12.73		B	
	Hockey	12.29		B	
Vertical Jump	**Hockey**	45.67	A		
	Runner	45.47	A		
	Netball	44.56	A	B	
	Soccer	41.88		B	
	Tennis	37.00			C
Medicine Ball Chest Throw	**Runner**	4.45	A		
	Hockey	4.44	A		
	Netball	4.35	A		
	Soccer	4.27	A		
	Tennis	3.88		B	

[b]Mean estimates from one-way analysis of variance (ANOVA) model with sport as fixed effect.

[c]Means sharing the same letter are not statistically different from each other at 0.05 significance level; pairs of means that do not share a letter show statistically significant differences.

Table 4.21: Pairwise P-values comparing sports with regard to athletic performance (Table 4.21 continues on next page)

Dependent Variable	Sport	Hockey	Netball	Runner	Soccer	Tennis
40 m sprint	**Hockey**		0.0598	0.0449*	0.3142	0.1649
	Netball	0.0598		0.0006*	0.3989	0.7871
	Runner	0.0449*	0.0006*		0.0064*	0.0039*
	Soccer	0.3142	0.3989	0.0064*		0.6260
	Tennis	0.1649	0.7871	0.0039*	0.6260	

T-Test	**Hockey**		0.0758	0.0693	0.0507	<0.0001*
	Netball	0.0758		0.9440	0.8903	0.0212*
	Runner	0.0693	0.9440		0.9486	0.0268*
	Soccer	0.0507	0.8903	0.9486		0.0268*
	Tennis	<0.0001*	0.0212*	0.0268*	0.0268*	
Vertical Jump	**Hockey**		0.4018	0.8814	0.0043*	<0.0001*
	Netball	0.4018		0.5371	0.0617	<0.0001*
	Runner	0.8814	0.5371		0.0148*	<0.0001*
	Soccer	0.0043*	0.0617	0.0148*		0.0026*
	Tennis	<0.0001*	<0.0001*	<0.0001*	0.0026*	
Medicine Ball Chest Throw	**Hockey**		0.5551	0.9453	0.2264	0.0011*
	Netball	0.5551		0.5534	0.5768	0.0096*
	Runner	0.9453	0.5534		0.2516	0.0023*
	Soccer	0.2264	0.5768	0.2516		0.0321*
	Tennis	0.0011*	0.0096*	0.0023*	0.0321*	

The display in Table 4.20 shows that netball, tennis, soccer and hockey do not show statistically significant differences from each other with regard to the 40 m sprint characteristic of athletic performance, but for this variable, running shows a statistically significant difference from this group of sports (netball, tennis, soccer and hockey; see pairwise P-values in Table 4.21). Thus, the 40 m sprint value of athletic performance is significantly lower for running than for the other four sports. With regard to the T-test and medicine ball chest throw characteristics of athletic performance, soccer, running, netball and hockey do not show a statistically significant difference from each other (see pairwise P-values in Table 4.21), but tennis does show a statistically significant difference from this group of sports (soccer, running, netball and hockey; see pairwise P-values in Table 4.21) and the mean value for tennis is significantly lower for these two variables. Table 4.20 also shows that hockey, running and netball do not show statistically significant differences from each other with regard to the vertical jump characteristic of athletic performance (see pairwise P-values in Table 4.21). Similarly, netball and soccer do not show statistically significant differences from each other, but soccer does show statistically significant differences from hockey and tennis, respectively. As before, tennis shows a statistically significant difference from all four sports (hockey, running, netball and soccer; see pairwise P-values in Table 4.21), having the lowest mean value for the vertical jump.

4.7 CORRELATIONS

4.7.1 Correlation between core strength and athletic performance

Overall, for all sports, and separately for each sport, Table 4.22 presents the Pearson correlation coefficients between the three characteristics of core strength and the four characteristics of athletic performance, together with the associated P-values.

Table 4.22: Correlation between core strength and athletic performance: Overall and by type of sport (Table 4.22 continues on next page)

Dependent Variable	Sport	N	Statistic	40 m sprint	T-Test	Vertical Jump	Medicine Ball Chest Throw
IBE	**All**	83	Pearson correlation	-0.13	-0.44	0.38	0.36
			P-value	0.2582	<0.0001*	0.0004*	0.0010*
	Hockey	24	Pearson correlation	0.05	-0.38	0.33	0.54
			P-value	0.8298	0.0655	0.1183	0.0069*
	Netball	16	Pearson correlation	0.16	-0.13	-0.48	-0.42
			P-value	0.5514	0.6371	0.0607	0.1020
	Runner	15	Pearson correlation	-0.36	-0.33	0.40	0.13
			P-value	0.1909	0.2295	0.1389	0.6387
	Soccer	17	Pearson correlation	-0.30	-0.52	0.63	0.55
			P-value	0.2453	0.0331*	0.0063*	0.0227*
	Tennis	11	Pearson correlation	-0.74	-0.59	0.25	0.58
			P-value	0.0094*	0.0548	0.4533	0.0597
LF	**All**	83	Pearson correlation	-0.10	-0.39	0.90	0.51
			P-value	0.3549	0.0003*	0.0002*	<0.0001*
	Hockey	24	Pearson correlation	-0.12	-0.50	0.37	0.61
			P-value	0.5811	0.0139*	0.0714	0.006*

	Netball	16	Pearson correlation	0.62	0.56	-0.51	-0.30
			P-value	0.0100*	0.0233*	0.0458*	0.2616
	Runner	15	Pearson correlation	-0.41	-0.44	0.56	0.63
			P-value	0.1247	0.1036	0.0307*	0.0119*
	Soccer	17	Pearson correlation	-0.30	-0.05	0.53	0.63
			P-value	0.2440	0.0407*	0.0300*	0.0070*
	Tennis	11	Pearson correlation	-0.56	-0.15	0.20	0.52
			P-value	0.0709	0.6600	0.5540	0.0996
AF	**All**	83	Pearson correlation	-0.05	-0.44	0.44	0.48
			P-value	0.6221	<0.0001*	<0.0001*	<0.0001*
	Hockey	24	Pearson correlation	0.12	-0.41	0.31	0.61
			P-value	0.5512	0.0491*	0.1430	0.0015*
	Netball	16	Pearson correlation	0.27	0.24	-0.06	-0.09
			P-value	0.3200	0.3671	0.8172	0.7458
	Runner	15	Pearson correlation	-0.37	-0.55	0.61	0.52
			P-value	0.1738	0.0329*	0.0163*	0.0478*
	Soccer	17	Pearson correlation	-0.34	-0.56	0.58	0.46
			P-value	0.1760	0.0196*	0.0140*	0.0626
	Tennis	11	Pearson correlation	-0.55	-0.43	-0.19	0.40

P-value	0.0802	0.1916	0.5752	0.2248

4.7.1.1 All sports: Correlation of core strength with athletic performance

Table 4.22 shows that, for all sports, all three characteristics of core strength have, as one would expect, a negative correlation with the 40 m sprint (IBE: r=-0.13; LF: r=-0.10; AF: r=-0.05) and the T-test (IBE: r=-0.44; LF: r=-0.39; AF: r=-0.44), and a positive correlation with the vertical jump (IBE: r=0.38; LF: r=0.9; AF: r=0.44) and the medicine ball chest throw (IBE: r=0.36; LF: r=0.51; AF: r=0.48). The negative correlations indicate that higher core strength leads to increased running speed and, therefore, decreased running times, whereas the positive correlations indicate that higher core strength leads to higher distances in both explosive power tests.

The correlation of all three characteristics of core strength with the 40 m sprint is weak (r<0.2) and moderately weak for the T-test (r=0.2-0.5). With regard to the IBE and AF characteristics of core strength, the correlation is moderately weak for the vertical jump and the medicine ball chest throw (r=0.2-0.5), moderately strong for the LF characteristic of the medicine ball chest throw (r=0.5-0.8) and strong for the LF characteristic of the vertical jump (r=0.8-1.0). All these correlations are statistically significant, except the correlations of the core strength characteristics with the 40 m sprint.

4.7.1.2 Hockey: Correlation of core strength with athletic performance

Table 4.22 shows that for hockey, all three characteristics of core strength have a negative correlation with the T-test (IBE: r=-0.38; LF: r=-0.50; AF: r=-0.41) and the 40 m sprint for the LF characteristic (r=-0.12), and a positive correlation with the vertical jump (IBE: r=0.33; LF: r=0.37; AF: r=0.31), the medicine ball chest throw (IBE: r=0.54; LF: r=0.61; AF: r=0.61) and the 40 m sprint for the IBE (r=0.05) and AF (r=0.12) characteristics. The negative correlations of core strength with running speed are as expected, as are the positive correlations of core strength with the explosive power tests. However, the positive correlations of IBE and AF with the 40 m sprint are not as expected.

The correlation of all three characteristics of core strength with the T-test and vertical jump is moderately weak (r=0.2-0.5), weak for the 40 m sprint (r<0.2) and moderately strong for the medicine ball chest throw (r=0.5-0.8). All these correlations are statistically significant, except the correlations of the core strength characteristics with the 40 m sprint and vertical jump, and the correlation of the IBE characteristic with the T-test are not statistically significant.

4.7.1.3 Netball: Correlation of core strength with athletic performance

Table 4.22 shows that for netball, all three characteristic of core strength have a negative correlation with the vertical jump (IBE: r=-0.48; LF: r=-0.51; AF: r=-0.06), medicine ball chest throw (IBE: r=-0.42; LF: r=-0.30; AF: r=-0.09) and the T-test for the IBE characteristic (r=-0.13), and a positive correlation with the 40 m sprint (IBE: r=0.16; LF: r=0.62; AF: r=0.27) and the T-test (LF: r=0.56; AF: r=0.24). The negative correlations of core strength with the explosive power tests are not as expected, as are the positive correlations of core strength with running speed. However, the negative correlation of IBE with the T-Test is as expected.

The correlation of the IBE characteristic of core strength with the 40 m sprint and T-test and of the AF characteristic with the vertical jump and medicine ball chest throw is weak (r<0.2), moderately weak for the IBE characteristic with the vertical jump and medicine ball chest throw, the LF characteristic with the medicine ball chest throw and the AF characteristic with the 40 m sprint and T-Test (r=0.2-0.5) and moderately strong for the LF characteristic with the 40 m sprint, the T-Test and vertical jump. These correlations are not statistically significant, except the correlations of the LF characteristic with the 40 m sprint, the T-test and vertical jump.

4.7.1.4 Runner: Correlation of core strength with athletic performance

Table 4.22 displays that for runners, all three characteristics of core strength have a negative correlation with the 40 m sprint (IBE: r=-0.36 LF: r=-0.41; AF: r=-0.37) and the T-test (IBE: r=-0.33; LF: r=-0.44; AF: r=-0.55) and a positive correlation with the vertical jump (IBE: r=0.40; LF: r=0.56; AF: r=0.61) and the medicine ball chest throw (IBE: r=0.13; LF: r=0.63; AF: r=0.52). The negative correlations of core strength with running speed are as expected, as are the positive correlations of core strength with the explosive power tests.

The correlation of the IBE characteristic of core strength with the medicine ball chest throw is weak (r<0.2), moderately weak for the IBE characteristic with the 40 m sprint, the T-Test and vertical jump, the LF characteristic with the 40 m sprint and T-test and the AF characteristic with the 40 m sprint (r=0.2-0.5) and moderately strong for the LF characteristic with the vertical jump and medicine ball chest throw and for the AF characteristic with the T-Test, the vertical jump and medicine ball chest throw (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of the LF characteristic with the vertical jump and medicine ball chest throw and the correlations of the AF characteristic with the T-test, the vertical jump and medicine ball chest throw which are statistically significant.

4.7.1.5 Soccer: Correlations of core strength with athletic performance

Table 4.22 displays that for soccer all three characteristics of core strength have a negative correlation with the 40 m sprint (IBE: r=-0.30; LF: r=-0.30; AF: r=-0.34) and the T-Test (IBE: r=-0.52; LF: r=-0.05; AF: r=-0.56) and a positive correlation with the vertical jump (IBE: r=0.63; LF: r=0.53; AF: r=0.58) and the medicine ball chest throw (IBE: r=0.55; LF: r=0.63; AF: r=0.46). The negative correlations of core strength with running speed are as expected, as are the positive correlations of core strength with the explosive power tests.

The correlation of the LF characteristic of core strength with the T-Test is weak (r<0.2), moderately weak for all three characteristics with the 40 m sprint and of the AF characteristic with the medicine ball chest throw (r=0.2-0.5) and moderately strong for the IBE characteristic with the T-Test, the vertical jump and medicine ball chest throw, for the LF characteristic with the vertical jump and medicine ball chest throw and for the AF characteristic with the T-test and vertical jump (r=0.5-0.8). All these correlations are statistically significant, except the correlations of the core strength characteristics with 40 m sprint which are not statistically significant.

4.7.1.6 Tennis: Correlations of core strength with athletic performance

Table 4.22 shows that for tennis, all three characteristics of core strength have a negative correlation with the 40 m sprint (IBE: r=-0.74; LF: r=-056.; AF: r=-0.55), the T-Test (IBE: r=-0.59; LF: r=-0.15; AF: r=-0.43) and vertical jump (AF: r=-0.19) and a positive correlation with the vertical jump (IBE: r=0.25; LF: r=0.20) and medicine ball chest throw (IBE: r=0.58; LF: r=0.52; AF: r=0.40). The negative correlations of core strength with running speed are as expected, as are the positive correlations of core strength with the explosive power tests. However, the negative correlation of AF with the vertical jump is not as expected.

The correlation of the LF characteristic of core strength with the T-Test and of the AF characteristic with the vertical jump is weak (r<0.2), moderately weak for LF characteristic with the vertical jump and the AF characteristic with the T-Test and medicine ball chest throw (r=0.2-0.5) and moderately strong for the IBE characteristic with the 40 m sprint, the T-Test and medicine ball chest throw, for the AF characteristic with the 40 m sprint and medicine ball chest throw and the LF characteristic with the 40 m sprint (r=0.5-0.8). None of these correlations are statistically significant, except the correlation of the IBE characteristic with the 40 m sprint which is statistically significant.

4.7.2 Correlation between core endurance and athletic performance

Overall, for all sports, and separately for each sport, Table 4.23 presents the Pearson correlation coefficients between the three characteristics of core endurance and the four characteristics of athletic performance, together with the associated P-values.

Table 4.23: Correlation between core endurance and athletic performance: Overall and by type of sport (Table 4.23 continues on next page)

Dependent Variable	Sport	N	Statistic	40 m	T-Test	Vertical Jump	Medicine Ball Chest Throw
IBE	**All**	83	Pearson correlation	-0.16	0.10	-0.14	-0.09
			P-value	0.1579	0.3677	0.2069	0.4189
	Hockey	24	Pearson correlation	-0.26	-0.19	0.15	0.05
			P-value	0.2181	0.3711	0.4866	0.8261
	Netball	16	Pearson correlation	0.30	0.17	-0.18	-0.01
			P-value	0.2581	0.5291	0.5164	0.9705
	Runner	15	Pearson correlation	0.33	0.15	-0.23	-0.31
			P-value	0.2289	0.5959	0.4188	0.2479
	Soccer	17	Pearson correlation	0.12	0.04	-0.15	0.16
			P-value	0.6532	0.8907	0.5670	0.5341
	Tennis	11	Pearson correlation	-0.67	-0.31	0.28	0.48
			P-value	0.0255*	0.3578	0.4019	0.1310
LF	**All**	83	Pearson correlation	-0.28	-0.06	0.05	0.09
			P-value	0.0105*	0.5922	0.6503	0.4288
	Hockey	24	Pearson correlation	-0.29	-0.34	-0.00	-0.00
			P-value	0.1694	0.0988	0.9887	0.9920

	Netball	16	Pearson correlation	-0.11	-0.11	-0.08	-0.06
			P-value	0.6786	0.6815	0.7570	0.8051
	Runner	15	Pearson correlation	0.21	0.49	0.11	0.00
			P-value	0.4617	0.0663	0.6961	0.9900
	Soccer	17	Pearson correlation	-0.07	-0.06	-0.08	0.27
			P-value	0.7750	0.8263	0.7547	0.2871
	Tennis	11	Pearson correlation	-0.43	-0.35	0.22	0.58
			P-value	0.1894	0.2939	0.5230	0.0594
AF	**All**	83	Pearson correlation	-0.35	-0.18	0.34	0.27
			P-value	0.0012*	0.1013	0.0019*	0.0127*
	Hockey	24	Pearson correlation	-0.25	-0.21	0.15	0.18
			P-value	0.2428	0.3177	0.4809	0.4042
	Netball	16	Pearson correlation	-0.20	-0.38	0.19	0.44
			P-value	0.4510	0.1485	0.4841	0.0899
	Runner	15	Pearson correlation	-0.03	-0.02	0.71	0.34
			P-value	0.2683	0.9496	0.0028*	0.2172
	Soccer	17	Pearson correlation	-0.09	-0.26	0.41	0.15
			P-value	0.7384	0.3059	0.1012	0.5554
	Tennis	11	Pearson correlation	-0.32	0.02	0.25	0.24

P-value	0.3447	0.9489	0.4573	0.4781

4.7.2.1 All sports: Correlation of core endurance with athletic performance

Table 4.23 shows that for all sports all three characteristics of core endurance have a negative correlation with the 40 m sprint (IBE: r=-0.16; LF: r=-0.28; AF: r=-0.35), the T-test (LF: r=-0.06; AF: r=-0.18), the vertical jump (IBE: r=-0.14) and medicine ball chest throw (IBE: r=-0.09) and a positive correlation with the T-Test (IBE: r=0.10), the vertical jump (LF: r=0.05; AF: r=0.34) and medicine ball chest throw (LF: r=0.09; AF: r=0.27). The negative correlations indicate that higher core endurance leads to increased running speed and therefore decreased running times, whereas the positive correlations indicate that higher core endurance leads to higher distances in both explosive power tests. The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests. However, the negative correlations of IBE with the vertical jump and medicine ball chest throw are not as expected, as are the positive correlations of IBE with the T-Test.

The correlation between all three characteristics of core endurance and the T-test, of IBE and LF with the vertical jump and medicine ball chest throw and of IBE with the 40 m sprint is weak (r<0.2) and moderately weak for LF and AF with the 40 m sprint and for AF with the vertical jump and medicine ball chest throw (r=0.2-0.5). None of these correlations are statistically significant, except the correlations of the LF and AF characteristics with the 40 m sprint and of the AF characteristic with the vertical jump and medicine ball chest throw which are statistically significant.

4.7.2.2 Hockey: Correlation of core endurance with athletic performance

Table 4.23 shows that for hockey, all three characteristics of core endurance have a negative correlation with the 40 m sprint (IBE: r=-0.26; LF: r=-0.29; AF: r=-0.25) and the T-test (IBE: r=-0.19; LF: r=-0.34; AF: r=-0.21), a positive correlation with the vertical jump (IBE: r=0.15; AF: r=0.15) and medicine ball chest throw (IBE: r=0.05; AF: r=0.18) and no correlation with the vertical jump (LF: r=0) and medicine ball chest throw (LF: r=0). The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests. However, the zero correlations of LF with the vertical jump and medicine ball chest throw are not as expected.

The correlation of IBE and AF characteristics of core endurance with the vertical jump and medicine ball chest throw and of IBE characteristic with the T-test is weak (r<0.2), moderately weak for all three characteristics with the 40 m sprint and for the LF and AF characteristics with the T-Test (r=0.2-0.5). None of these correlations are statistically significant.

4.7.2.3 Netball: Correlation of core endurance with athletic performance

Table 4.23 shows that for netball, all three characteristics of core endurance have a negative correlation with the 40 m sprint (LF: r=-0.11; AF: r=-0.20), the T-test (LF: r=-0.11; AF: r=-0.38), the vertical jump (IBE: r=-0.18; LF: r=-0.08) and medicine ball chest throw (IBE: r=-0.01; LF: r=-0.06) and a positive correlation with the 40 m sprint (IBE: r=0.30), the T-test (IBE: r=0.17), the vertical jump (AF: r=0.19) and medicine ball chest throw (AF: r=0.44). The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests. However, neither the negative correlations of IBE and LF with the vertical jump and medicine ball chest throw are as expected, nor are the positive correlations of IBE characteristic with the 40 m sprint and T-Test.

The correlation between all three characteristics of core endurance and the vertical jump, of IBE and LF with the T-Test and medicine ball chest throw and of LF with the 40 m sprint is weak (r<0.2) and moderately weak for the IBE and AF characteristics with the 40 m sprint and AF characteristic with the T-Test and medicine ball chest throw (r=0.2-0.5). None of these correlations are statistically significant.

4.7.2.4 Runner: Correlation of core endurance with athletic performance

Table 4.23 shows that for runners the IBE and AF characteristics of core endurance have a negative correlation with the 40 m sprint (AF: r=-0.03), the T-test (AF: r=-0.02), the vertical jump (IBE: r=-0.23) and medicine ball chest throw (IBE: r=-0.31). With regard to all three characteristics of core endurance, the correlation is positive for the 40 m sprint (IBE: r=0.33; LF: r=0.21), the T-test (IBE: r=0.15; LF: r=0.49), the vertical jump (LF: r=0.11; AF: r=0.71) and medicine ball chest throw (AF: r=0.34) and zero for the LF characteristic with the medicine ball chest throw LF: r=0). The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests.

However, neither the negative correlations of IBE with the vertical jump and medicine ball chest throw are as expected, nor are the positive correlations of IBE and LF characteristics with the 40 m sprint and T-Test and the zero correlation of LF with the medicine ball chest throw.

The correlation of the IBE and AF characteristics of core endurance with the T-Test, of LF characteristic with the vertical jump and the AF characteristic with the 40 m sprint is weak (r<0.2), moderately weak for the IBE and AF characteristics with the vertical jump and medicine ball chest throw, for the IBE and LF characteristics and the 40 m sprint and the LF characteristic with the T-Test (r=0.2-0.5) and moderately strong for the AF characteristic with the vertical jump (r=0.5-0.8). None of these correlations are statistically significant, except the correlation of the AF characteristic with the vertical jump which is statistically significant.

4.7.2.5 Soccer: Correlation of core endurance with athletic performance

Table 4.23 shows that for soccer, all three characteristics of core endurance have a negative correlation with the 40 m sprint (LF: r=-0.07; AF: r=-0.09), the T-test (LF: r=-0.06; AF: r=-0.26) and vertical jump (IBE: r=-0.15; LF: r=-0.08) and a positive correlation with the 40 m sprint (IBE: r=0.12), the T-test (IBE: r=0.04), the vertical jump (AF: r=0.41) and medicine ball chest throw (IBE: r=0.16; LF: r=0.27; AF: r=0.15). The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests. However, neither the negative correlations of IBE and LF with the vertical jump are as expected, nor are the positive correlations of IBE characteristic with the 40 m sprint and T-Test.

The correlation between all three characteristics of core endurance and the 40 m sprint, of IBE and LF characteristics with the T-Test and vertical jump and of IBE and AF characteristics with the medicine ball chest throw is weak (r<0.2) and moderately weak for the LF characteristic with the medicine ball chest throw and the AF characteristic with the T-Test and vertical jump (r=0.2-0.5). None of these correlations are statistically significant.

4.7.2.6 Tennis: Correlation of core endurance with athletic performance

Table 4.23 shows that for tennis, all three characteristics of core endurance have a negative correlation with the 40 m sprint (IBE: r=-0.67; LF: r=-0.43; AF: r=-0.32) and the T-test (IBE: r=-

0.31; LF: r=-0.35) and a positive correlation with the vertical jump (IBE: r=0.28; LF: r=0.22; AF: r=0.25), the medicine ball chest throw (IBE: r=0.48; LF: r=0.58; AF: r=0.24) and T-Test (AF: r=0.02). The negative correlations of core endurance with running speed are as expected, as are the positive correlations of core endurance with the explosive power tests. However, the positive correlation of the AF characteristic with the T-Test is not as expected.

The correlation of the AF characteristic of core endurance with the T-Test is weak (r<0.2), moderately weak for all three characteristics with the vertical jump, for the LF and AF characteristics with the 40 m sprint, for the IBE and LF characteristics with the T-Test and the IBE and AF characteristics with the medicine ball chest throw (r=0.2-0.5) and moderately strong for the IBE characteristic with the 40 m sprint and the LF characteristic with the medicine ball chest throw (r=0.5-0.8). None of these correlations are statistically significant, except the correlation of the IBE characteristic with the 40 m sprint which is statistically significant.

4.7.3 Correlation between core motor control and athletic performance

Overall, for all sports, and separately for each sport, Table 4.24 presents the Pearson correlation coefficients between core motor control and the four characteristics of athletic performance, together with the associated P-values.

Table 4.24: Correlation between core motor control and athletic performance: Overall and by type of sport (Table 4.24 continues on next page)

Dependent Variable	Sport	N	Statistic	40 m	T-Test	Vertical Jump	Medicine Ball Chest Throw
NMC	**All**	83	Pearson correlation	-0.32	-0.12	-0.05	-0.05
			P-value	0.0032*	0.2703	0.6831	0.6510
	Hockey	24	Pearson correlation	-0.24	-0.11	0.04	-0.14
			P-value	0.2662	0.6058	0.8458	0.4992
	Netball	16	Pearson correlation	-0.06	-0.04	-0.25	-0.30
			P-value	0.8137	0.8814	0.3593	0.2523
	Runner	15	Pearson correlation	0.37	-0.14	-0.27	-0.04
			P-value	0.1687	0.6310	0.3320	0.8842
	Soccer	17	Pearson correlation	-0.55	-0.56	0.44	0.36
			P-value	0.0222*	0.0200*	0.0781	0.1543
	Tennis	11	Pearson correlation	-0.35	-0.09	0.49	0.23
			P-value	0.2942	0.7957	0.1281	0.4916

4.7.3.1 All sports: Correlation of core motor control with athletic performance

Table 4.24 shows that for all sports, the characteristic of core motor control has a negative correlation with the 40 m sprint (r=-0.32), the T-test (r=-0.12), the vertical jump (r=-0.05) and medicine ball chest throw (r=-0.05). The negative correlations of core motor control with running speed are as expected. However, the negative correlations of core motor control with the explosive power tests are not as expected.

The correlation of core motor control with the T-test, the vertical jump and medicine ball chest throw is weak (r<0.2) and moderately weak for the 40 m sprint (r=0.2-0.5). All these correlations are statistically significant, except the correlation of core motor control with the 40 m sprint which is not statistically significant.

4.7.3.2 Hockey: Correlation of core motor control with athletic performance

Table 4.24 shows that for hockey, the characteristic of core motor control has a negative correlation with the 40 m sprint (r=-0.24), the T-test (r=-0.11) and medicine ball chest throw (r=-0.14) and a positive correlation with the vertical jump (r=0.04). The negative correlations of core motor control with running speed are as expected, as are the positive correlation with the vertical jump. However, the negative correlation of core motor control with the medicine ball chest throw is not as expected.

The correlation of core motor control with the T-test, the vertical jump and medicine ball chest throw is weak (r<0.2) and moderately weak for the 40 m sprint (r=0.2-0.5). None of these correlations are statistically significant.

4.7.3.3 Netball: Correlation of core motor control with athletic performance

Table 4.24 shows that for netball, the characteristic of core motor control has a negative correlation with the 40 m sprint (r=-0.06), the T-test (r=-0.04), the vertical jump (r=-0.25) and medicine ball chest throw (r=-0.30). The negative correlations of core motor control with running speed are as expected. However, the negative correlations of core motor control with the explosive power tests are not as expected.

The correlation of core motor control with the 40 m sprint and T-test is weak (r<0.2) and moderately weak for the vertical jump and medicine ball chest throw (r=0.2-0.5). None of these correlations are statistically significant.

4.7.3.4 Runner: Correlation of core motor control with athletic performance

Table 4.24 shows that for running, the characteristic of core motor control has a negative correlation with the T-test (r=-0.14), the vertical jump (r=-0.27) and medicine ball chest throw (r=-0.04) and a positive correlation with the 40 m sprint (r=0.37). The negative correlations of core motor control with running speed are as expected. However, neither the negative correlations of core motor control with the explosive power tests are as expected, nor is the positive correlation with the 40 m sprint.

The correlation of core motor control with the T-test and medicine ball chest throw is weak (r<0.2) and moderately weak for the 40 m sprint and vertical jump (r=0.2-0.5). None of these correlations are statistically significant.

4.7.3.5 Soccer: Correlation of core motor control with athletic performance

Table 4.24 shows that for soccer, the characteristic of core motor control has a negative correlation with the 40 m sprint (r=-0.55) and T-test (r=-0.56) and a positive correlation with the vertical jump (r=0.44) and medicine ball chest throw (r=0.36). The negative correlations of core motor control with running speed are as expected, as are the positive correlations with both the explosive power tests.

The correlation of core motor control with the vertical jump and medicine ball chest throw is moderately weak (r=0.2-0.5) and moderately strong for the 40 m sprint and T-Test (r=0.5-0.8). All these correlations are statistically significant, except the correlation of core motor control with the medicine ball chest throw which is not statistically significant.

4.7.3.6 Tennis: Correlation of core motor control with athletic performance

Table 4.24 shows that for tennis, the characteristic of core motor control has a negative correlation with the 40 m sprint (r=-0.35) and T-test (r=-0.09) and a positive correlation with the vertical jump (r=0.49) and medicine ball chest throw (r=0.23). The negative correlations of core motor control with running speed are as expected, as are the positive correlations with both the explosive power tests.

The correlation of core motor control with the T-Test is weak ($r<0.2$) and moderately weak for the 40 m sprint, the vertical jump and medicine ball chest throw ($r=0.2$-0.5). None of these correlations are statistically significant.

4.7.4 Correlation between anthropometric characteristics and athletic performance

Overall, for all sports, and separately for each sport, Table 4.25 presents the Pearson correlation coefficients between the five anthropometric characteristics and the four characteristics of athletic performance, together with the associated P-values.

Table 4.25: Correlation between anthropometric characteristics and athletic performance: Overall and by type of sport (Table 4.25 continues on next page)

Dependent Variable	Sport	N	Statistic	40 m	T-Test	Vertical Jump	Medicine Ball Chest Throw
Age	**All**	83	Pearson correlation	-0.04	-0.20	0.03	-0.02
			P-value	0.7027	0.0659	0.8099	0.8248
	Hockey	24	Pearson correlation	-0.21	-0.43	0.16	0.13
			P-value	0.3136	0.0368*	0.4465	0.5302
	Netball	16	Pearson correlation	-0.18	-0.08	0.18	0.08
			P-value	0.5000	0.7805	0.5009	0.7642
	Runner	15	Pearson correlation	0.04	-0.19	0.43	0.02
			P-value	0.8875	0.7969	0.1068	0.9300
	Soccer	17	Pearson correlation	-0.15	-0.09	0.13	-0.06
			P-value	0.5627	0.7294	0.6270	0.8274
	Tennis	11	Pearson correlation	0.01	0.13	-0.34	-0.21
			P-value	0.9670	0.7128	0.3102	0.5391
Height	**All**	83	Pearson correlation	-0.08	0.05	0.13	0.24
			P-value	0.4999	0.6618	0.2483	0.0279
	Hockey	24	Pearson correlation	-0.13	0.13	0.24	0.19

			P-value	0.5319	0.5598	0.2626	0.3743
	Netball	16	Pearson correlation	0.25	0.24	-0.12	-0.04
			P-value	0.3515	0.3634	0.6645	0.8951
	Runner	15	Pearson correlation	-0.02	-0.12	0.13	0.50
			P-value	0.9391	0.6595	0.6410	0.0598
	Soccer	17	Pearson correlation	0.15	0.28	-0.22	-0.02
			P-value	0.5592	0.2850	0.3983	0.9427
	Tennis	11	Pearson correlation	-0.23	-0.04	-0.27	0.02
			P-value	0.4891	0.9072	0.4225	0.9455
Weight	**All**	83	Pearson correlation	0.38	0.27	-0.07	0.04
			P-value	0.0005*	0.0151*	0.5417	0.7380
	Hockey	24	Pearson correlation	0.32	0.07	-0.03	0.29
			P-value	0.1221	0.7494	0.8933	0.1769
	Netball	16	Pearson correlation	0.64	0.63	-0.21	-0.20
			P-value	0.0078*	0.0094*	0.4333	0.4556
	Runner	15	Pearson correlation	-0.19	-0.27	0.55	0.60
			P-value	0.4985	0.3302	0.0335*	0.0171*
	Soccer	17	Pearson correlation	0.40	0.57	-0.54	-0.40
			P-value	0.1155	0.0164*	0.0261*	0.1147

	Tennis	11	Pearson correlation	0.08	0.49	0.41	-0.19
			P-value	0.8209	0.1283	0.2055	0.5721
Fat Percentage	**All**	83	Pearson correlation	0.61	0.17	-0.20	-0.16
			P-value	<0.0001*	0.1155	0.0694	0.1609
	Hockey	24	Pearson correlation	0.45	-0.03	-0.33	-0.01
			P-value	0.0268*	0.8940	0.1123	0.9806
	Netball	16	Pearson correlation	0.48	0.54	-0.28	-0.12
			P-value	0.0616	0.0296*	0.2968	0.6541
	Runner	15	Pearson correlation	0.14	-0.06	0.01	0.27
			P-value	0.6205	0.8397	0.9745	0.3394
	Soccer	17	Pearson correlation	0.76	0.68	-0.44	-0.64
			P-value	0.0004*	0.0028*	0.0775	0.0054*
	Tennis	11	Pearson correlation	0.45	0.24	-0.45	-0.49
			P-value	0.1601	0.4734	0.4696	0.1242
BMI	**All**	83	Pearson correlation	0.56	0.33	-0.24	-0.21
			P-value	<0.0001*	0.0024*	0.0289*	0.0546
	Hockey	24	Pearson correlation	0.52	0.06	-0.23	0.03
			P-value	0.0093*	0.7977	0.2735	0.8970

Netball	16	Pearson correlation	0.75	0.77	-0.45	-0.42
		P-value	0.0009*	0.0005*	0.0841	0.1084
Runner	15	Pearson correlation	-0.09	-0.11	0.36	0.34
		P-value	0.7466	0.7036	0.1844	0.2164
Soccer	17	Pearson correlation	0.61	0.58	-0.38	-0.66
		P-value	0.0096*	0.0146*	0.1295	0.0042*
Tennis	11	Pearson correlation	0.38	0.50	0.35	-0.56
		P-value	0.2466	0.1154	0.2942	0.0730

4.7.4.1 All sports: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for all sports, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Age: r=-0.04; Height: r=-0.08), the T-test (Age: r=-0.20), the vertical jump (Weight: r=-0.07; Fat: r=-0.20; BMI: r=-0.24) and medicine ball chest throw (Age: r=-0.02; Fat r=-0.16; BMI: r=-0.21) and a positive correlation with the 40 m sprint (Weight: r=0.38; Fat: r=0.61; BMI: r=0.56), the T-Test (Height: r=0.05; Weight: r=0.27; Fat: r=0.17; BMI: r=0.33), the vertical jump (Age: r=0.03; Height: r=0.13) and medicine ball chest throw (Height: r=0.24; Weight: r=0.04). The negative correlations of the anthropometric characteristics with the explosive tests are as expected. However, neither the positive correlations of the anthropometric characteristics with running speed are as expected, nor are the positive correlations with both explosive power tests.

The correlations of age characteristic with the 40 m sprint, the vertical jump and medicine ball chest throw, of height with the 40 m sprint, the T-Test and vertical jump, of weight with the vertical jump and medicine ball chest throw and of fat percentage with the T-Test and medicine ball chest throw is weak (r<0.2), moderately weak for age with the T-Test, for height with the medicine ball chest throw, for weight with the 40 m sprint and T-Test, for fat percentage with the vertical jump and for BMI with the T-Test, the vertical jump and medicine ball chest throw (r=0.2-0.5) and moderately strong for fat percentage and BMI with the 40 m sprint (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of height characteristic with the medicine ball chest throw, weight characteristic with the 40 m sprint and T-Test, fat percentage characteristic with the 40 m sprint and BMI characteristic with the 40 m sprint, the T-Test and vertical jump which are statistically significant.

4.7.4.2 Hockey: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for hockey, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Age: r=-0.21; Height: r=-0.13), the T-test (Age: r=-0.43; Fat: r=-0.03), the vertical jump (Weight: r=-0.03; Fat: r=-0.33; BMI: r=-0.23) and medicine ball chest throw (Fat r=-0.01) and a positive correlation with the 40 m sprint (Weight: r=0.32; Fat: r=0.45; BMI: r=0.52), the T-Test (Height: r=0.13; Weight: r=0.07; BMI: r=0.06), the vertical jump (Age: r=0.16; Height: r=0.24) and medicine ball chest throw (Age: r=0.13; Height: r=0.19; Weight: r=0.29; BMI: r=0.03). The negative correlations of the anthropometric characteristics with running speed are as expected, as are the negative correlations with both the explosive tests. However, neither the positive correlations of the anthropometric characteristics with running speed are as expected, nor are the positive correlations with both explosive power tests.

The correlations of age with the vertical jump and medicine ball chest throw, of height with the 40 m sprint, of weight with the vertical jump and of height, weight, fat percentage and BMI with the T-Test and medicine ball chest throw, respectively, are weak (r<0.2), moderately weak for age with the 40 m sprint and T-Test, for height with the vertical jump, for weight with the 40 m sprint and medicine ball chest throw, for fat percentage with the 40 m sprint and vertical jump and for BMI with the vertical jump (r=0.2-0.5), and moderately strong for the 40 m sprint with regard to the BMI characteristic (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of age characteristic with the T-Test and of the age, fat percentage and BMI characteristics with the 40 m sprint which are statistically significant.

4.7.4.3 Netball: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for netball, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Age: r=-0.18), the T-test (Age: r=-0.08), the vertical jump (Height: r=-0.12; Weight: r=-0.21; Fat: r=-0.28; BMI: r=-0.45) and medicine ball chest throw (Height: r=-0.04; Weight: r=-0.20; Fat r=-0.12; BMI: r=-0.42), and a positive correlation with the 40 m sprint (Height: r=0.25; Weight: r=0.64; Fat: r=0.48; BMI: r=0.75), the T-Test (Height: r=0.24; Weight: r=0.63; Fat: r=0.54; BMI: r=0.77), the vertical jump (Age: r=0.18) and medicine ball chest throw (Age: r=0.08). The negative correlations of the anthropometric characteristics with both the explosive tests are as expected. However, the positive correlations of the anthropometric characteristics with running speed are not as expected.

The correlations of age with the 40 m sprint, the T-Test and vertical jump, of height with the vertical jump and of age, height and fat percentage with the medicine ball chest throw are weak (r<0.2), moderately weak for height with the 40 m sprint and T-Test, for weight with the vertical jump and medicine ball chest throw, for fat percentage with the 40 m sprint and vertical jump and for BMI with the vertical jump and medicine ball chest throw (r=0.2-0.5), and moderately strong for the 40 m sprint with regard to weight and BMI characteristics and for the T-Test with regard to weight, fat percentage and BMI characteristics (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of weight and BMI characteristics with the 40 m sprint and T-Test and of fat percentage characteristic with the T-Test which are statistically significant.

4.7.4.4 Runner: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for runners, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Height: r=-0.02; Weight: r=-0.19; BMI: r=-0.09) and T-test (Age: r=-0.19; Height: r=-0.12; Weight: r=-0.27; Fat: r=-0.06; BMI: r=-0.11), and a positive correlation with the 40 m sprint (Age: r=0.04; Fat: r=0.14), the vertical jump (Age: r=0.43; Height: r=0.13; Weight: r=0.55; Fat: r=0.01; BMI: r=0.36) and medicine ball chest throw (Age: r=0.02; Height: r=0.50; Weight: r=0.60; Fat: r=0.27; BMI: r=0.34). The negative correlations of the anthropometric characteristics with running speed are as expected. However, neither the positive correlations of the anthropometric characteristics with running speed are as expected, nor are the positive correlations with both explosive power tests.

The correlations of age, height, fat percentage and BMI characteristics with the 40 m sprint and T-Test, of height and fat percentage characteristics with the vertical jump and of age with the medicine ball chest throw is weak (r<0.2), moderately weak for age and BMI with the vertical jump, for weight with the T-Test and for fat percentage and BMI with the medicine ball chest throw (r=0.2-0.5), and moderately strong for the vertical jump with regard to weight characteristic and for the medicine ball chest throw with regard to height and weight characteristics (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of weight characteristic with the vertical jump and medicine ball chest throw which are statistically significant.

4.7.4.5 Soccer: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for soccer, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Age: r=-0.15), the T-test (Age: r=-0.09), the vertical jump (Height: r=-0.22; Fat: r=-0.44; BMI: r=-0.38) and medicine ball chest throw (Age: r=-0.06;

Height: r=-0.02; Weight: r=-0.40; Fat: r=-0.64; BMI: r=-0.66), and a positive correlation with the 40 m sprint (Height: r=0.15; Weight: r=0.40; Fat: r=0.76; BMI: r=0.61), T-Test (Height: r=0.28; Weight: r=0.57; Fat: r=0.68; BMI: r=0.58) and vertical jump (Age: r=0.13). The negative correlations of the anthropometric characteristics with both explosive power tests are as expected. However, the positive correlations of the anthropometric characteristics with running speed are not as expected.

The correlations of age and height characteristics with the 40 m sprint and medicine ball chest throw and of age with the T-Test and vertical jump are weak (r<0.2), moderately weak for height, fat percentage and BMI characteristics with the vertical jump, of height with the T-Test and of weight with the 40 m sprint and medicine ball chest throw (r=0.2-0.5), and moderately strong for the 40 m sprint, the T-Test and medicine ball chest throw with regard to weight and BMI characteristics and for the T-Test with regard to the weight characteristic (r=0.5-0.8). None of these correlations are statistically significant, except the correlations of weight, fat percentage and BMI characteristics with the T-Test, of weight characteristic with the vertical jump and of fat percentage and BMI characteristics with the 40 m sprint and medicine ball chest throw which are statistically significant.

4.7.4.6 Tennis: Correlation of anthropometric characteristics with athletic performance

Table 4.25 shows that for tennis, all five anthropometric characteristics have a negative correlation with the 40 m sprint (Height: r=-0.23), T-test (Height: r=-0.04), the vertical jump (Age: r=-0.34; Height: r=-0.27; Fat: r=-0.45) and medicine ball chest throw (Age: r=-0.21; Weight: r=-0.19; Fat: r=-0.49; BMI: r=-0.56) and a positive correlation with the 40 m sprint (Age: r=0.01; Weight: r=0.08; Fat: r=0.45; BMI: r=0.38), the T-Test (Age: r=0.13; Weight: r=0.49; Fat: r=0.24; BMI: r=0.50), the vertical jump (BMI: r=0.35) and medicine ball chest throw (Height: r=0.02). The negative correlations of the anthropometric characteristics with running speed are as expected, as are the negative correlations with both the explosive tests. However, neither the positive correlations of the anthropometric characteristics with running speed are as expected, nor are the positive correlations with both explosive power tests.

The correlations of age, weight and BMI characteristics with the 40 m sprint, of age, height and fat percentage characteristics with the T-Test, of height and weight characteristics with the medicine ball chest throw and BMI characteristic with the vertical jump is weak (r<0.2), moderately weak for height with the 40 m sprint and vertical jump, for weight with the T-Test, for fat percentage with the 40 m sprint, the T-Test, the vertical jump and medicine ball chest throw and for BMI with the 40 m sprint and vertical jump (r=0.2-0.5), and moderately strong for the T-Test and medicine ball chest throw with regard to BMI characteristic (r=0.5-0.8). None of these correlations are statistically significant.

In conclusion, this study depicted the anthropometric profiles of female university athletes and found that runners have the greatest height and netball the greatest body weight, body fat percentage and BMI compared to the other sport codes. Furthermore, this study determined the relationship between core stability (i.e. core strength, core endurance, and core motor control) and found that the highest mean value for core strength was observed in hockey, and the highest mean values of core endurance and core motor control were observed in runners.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 INTRODUCTION

Core stability training is widely considered to be a main component in athletic training and, as previously stated, is thought to enhance athletic performance and decrease the risk of injury. It is hypothesised that core stability and athletic performance correlate. For example, Sharrock *et al*. (2011:71) conducted a study with the aim to evaluate the relationship of core stability with athletic performance among university athletes and found an apparent link between the DLLT, which is a core stability test, and athletic performance. However, the latest research does not completely confirm the correlation between core stability and athletic performance. The understanding of core stability in the athletic community is currently limited and should be improved in order to enable development of efficient training programmes to enhance athletic performance.

Existing research which investigated the relationship between core stability and athletic performance used a variety of core stability tests. These tests include the DLLT (Sharrock *et al*., 2011:71), the core flexor, extensor and lateral endurance tests (Tse *et al.,* 2005:549; McGill, 2010:40), the front- and side abdominal power tests (Cowley & Swensen, 2008:620), the back extension, trunk flexion and side bridge (Nesser *et al*., 2008:1752; Nesser & Lee, 2009:24) and the Sahrmann test and electromyography activity of abdominal and back muscles (Stanton *et al*., 2004:523). Furthermore, various athletic performance tests, including the vertical jump, 20 m and 40 m sprint and 10 m shuttle run (Nesser *et al*., 2008:1753), the 5000 m run (Sato & Mokha, 2009:137), the VO_2max (Stanton *et al*., 2004:526) and the vertical jump, broad jump, shuttle run, 40 m sprint, medicine ball throw and 2000 m maximal rowing ergometer test (Tse *et al*., 2005:548) were used in previous research.

To the researcher's knowledge, the current study is the first to determine the relationship between core stability and athletic performance using a battery of tests to assess the different components of core stability (strength, endurance and motor control). Core strength and endurance were assessed using the Bering-Sorensen tests, including the IBE, LF and AF tests, and core motor control using the Wisbey-Roth Core Stability Grading System. Athletic performance was assessed using the 40 m sprint, T-Test, vertical jump and the medicine ball chest throw. These four athletic performance tests were used in order to characterise speed, agility and explosive power performance during actual participation in hockey, netball, runners, soccer and tennis. This chapter will discuss the results of this study (Chapter 4) as well as the relationship between core stability and athletic performance.

5.2 ANTHROPOMETRIC CHARACTERISTICS

A well-trained athlete is expected to have skills such as speed, agility, explosive power and sport-specific attributes. Together with these skills, athletes competing at an elite level require a certain body composition, depending on their sport and position played. The body composition of athletes may vary within a team, although the players are generally similar in their skills, depending on their sport and position played. It is commonly known that the analysis of body composition is an important aspect to enhance sport performance in elite athletes (Durandt *et al.*, 2006:38). This study reports the five anthropometric characteristics, namely height, weight, BF% and BMI of female university athletes. Overall, the sports included in this study show a statistically significant difference with respect to four of the five anthropometric characteristics, but height does not show a statistically significant difference between sports (Table 4.3). Results therefore suggest that the anthropometric profile of athletes differs based on the sport code.

5.2.1 Height

This study reports a mean height of 1.68 m for female athletes, which varies from a minimum of 1.54 m for hockey to a maximum of 1.88 m for runners (Table 4.2). The mean height of runners (1.70 m) was the highest and tennis (1.66 m) the lowest. Hockey (1.67 m), soccer (1.68 m) and netball (1.69 m) do not show much variation in height. Furthermore, this study found that the sport codes included in this study did not show statistically significant differences from each other with regard to the height characteristic (Table 4.5).

Arazi *et al*. (2015:37) reported higher mean values for height (1.75 ± 0.07 m) in national Iranian cross-country runners, compared to this study, with 1.70 ± 0.07 m for runners. By comparison, Sharma and Kailashiya (2017:2) found young female Indian field hockey players to be shorter (1.55 ± 5.32 m) than female university hockey players in this study. A study conducted by Naicker *et al*. (2016:120) also reported South African female field hockey players to be shorter (1.64 ± 0.52 m) than female university hockey players in this study. In addition, Ferreira and Spamer (2010:61) reported a mean height of 1.75 ± 0.03 m in elite North-West University netball players, compared to this study, with 1.69 ± 0.05 m for netball. Sedano *et al*. (2009:390) found elite female Spanish National First Division soccer players to be shorter (1.61 ± 0.05 m) than female university soccer players in this study. Attlee *et al*. (2017:148) reported a mean height of 1.58 ± 0.03 m in female university tennis players in United Arab Emirates, compared to this study, with 1.66 ± 0.03 m for tennis.

To conclude, female university athletes in this research study show superior body height for hockey, soccer and tennis and inferior body height for netball and runners, respectively, compared to national and international female university athletes. An unexpected result of this study, with regard to height, is that netball players are not the tallest athletes, as it is assumed in the sport sector.

5.2.2 Body weight

This study reports a mean body weight of 63.05 kg for female university athletes. Netball showed the highest mean body weight of 66.40 kg and runners the lowest with 58.25 kg (Table 4.2). Hockey (63.69 kg), soccer (63.68 kg) and tennis (62.36 kg) do not show much variation in body weight. Furthermore, this study also found that hockey, netball, soccer and tennis do not show statistically significant differences from each other with regard to body weight (Table 4.5). Similarly, tennis and running do not show statistically significant differences from each other, but running does show statistically significant differences from netball, hockey and soccer, respectively (Table 4.5). The latter could be contributed to the nature of the sport, as runners train hard to sustain endurance and, consequently, burn almost all the calories they consume. The results reflect that body weight plays a major role amongst elite runners.

Ferreira and Spamer (2010:61) reported a higher mean body weight of 68.2 ± 0.01 kg for elite North-West University netball players compared to this study (66.40 ± 8.61 kg). Arazi *et al*. (2015:37) found national Iranian female cross-country runners to have higher body weight (63.55 ± 8.71 kg) than female university runners in this study. Sharma and Kailashiya (2017:2) reported a lower mean body weight (51.17 ± 7.69 kg) in young Indian field hockey players, compared to this study, with 63.69 ± 7.51 kg for university hockey players. Similarly, Naicker *et al*. (2016:120) found South African female field hockey players to have lower body weight (62.6 ± 8.45 kg) when compared to female university hockey players in this study. Sedano *et al.* (2009:390) noted a much lower mean body weight of 57.7 ± 7.5 kg for elite Spanish National First Division soccer players compared to this study (63.68 ± 5.30 kg). Attlee *et al.* (2017:148) reported a mean body weight of 52.6 ± 3.2 kg in United Arab Emirates female university tennis players, compared to this study, with 62.36 ± 2.97 kg for university tennis players.

To conclude, female university athletes in this study demonstrate higher body weight for hockey, soccer and tennis, and lower body weight for netball and runners, respectively, compared to national and international female university athletes. Furthermore, the results conclude that body weight differs between the various sport codes.

5.2.3 Body fat percentage and BMI

The results of the current study suggest that the mean BF% of female university athletes is 21.95%, with netball (24.09%) exceeding those of hockey (22.37%), runners (18.47%), soccer (22.47%) and tennis (21.87%) (Table 4.2). This study also found that, for BF%, netball, soccer and hockey do not show statistically significant differences from each other, as well as soccer, hockey and tennis which do not show statistically significant differences from each other. However, running shows statistically significant differences from netball, soccer, hockey and tennis (Table 4.5). Furthermore, the results of this study suggest that low BF% is an important characteristic in elite runners, as it is hypothesised in the sport sector.

Ferreira and Spamer (2010:61) reported a higher BF% (26.6 ± 0.43%) in elite North-West University netball players than female university netball players in this study (24.09 ± 3.62%). Similarly, Sharma and Kailashiya (2017:2) found a higher BF% of 24.92 ± 3.91% in young Indian field hockey players, compared to this study, with 22.37 ± 3.10% for female university hockey players. Arazi *et al*. (2015:37) reported national Iranian cross-country runners to have much lower BF% (8.07 ± 1.71%) than female university runners in this study (18.47 ± 2.07%). Similarly, Sedano *et al.* (2009:390) noted a much lower mean BF% of 20.10 ± 5.5% for elite Spanish National First Division soccer players compared to this study (22.47 ± 2.53%). Attlee *et al.* (2017:148) reported a significantly higher mean BF% of 40.9 ± 6.9 in United Arab Emirates female university tennis players, compared to this study, with 21.87 ± 2.15% for university tennis players. Arabi *et al*. (2004:1428) demonstrated that body weight is greater in males than females, whereas BF% is greater in females.

Although a certain amount of body fat functions as an energy source during activity, it serves as additional body weight that does not promote muscle explosive power generation, and therefore will have an influence on sprinting and jumping ability, reducing sport performance. Consequently, it is important to maintain an optimal BF%, specific to the sport and position played. The BF% of athletes who participated in this research study were higher than the standard for elite female athletes (14-20%), as reported in a study by Withers *et al*. (1987:173).

In the current study, BMI corresponds with BF%. Netball players show greater mean BMI (23.20 $kg.m^{-2}$) compared to hockey (22.78 $kg.m^{-2}$), runners (20.09 $kg.m^{-2}$), soccer (22.49 $kg.m^{-2}$) and tennis (22.59 $kg.m^{-2}$), whilst the mean BMI of female university athletes is 22.29 $kg.m^{-2}$. This study also found that netball, hockey, tennis and soccer do not show statistically significant differences from each other with regard to BMI, but for this variable, running shows a statistically significant difference from netball, hockey, tennis and soccer (Table 4.5). Similar to BF%, a lower BMI in elite runners was found as an important characteristic of an athlete. These results support the assumption in the sport sector that runners should have lower values for BMI due to the endurance component of the sport code, which results in the burn of almost all calories consumed.

Ferreira and Spamer (2010:61) noted a lower BMI of 22.37 ± 0.6 $kg.m^{-2}$ in elite North-West University netball players than female university netball players in this study (23.20 ± 2.13 $kg.m^{-2}$). Similarly, Sharma and Kailashiya (2017:2) reported a lower BMI of 21.14 ± 1.82 $kg.m^{-2}$ in young Indian field hockey players, compared to this study, with 22.78 ± 3.16 $kg.m^{-2}$ for female university hockey players. Arazi *et al*. (2015:37) found national Iranian cross-country runners to have greater BMI (20.63 ± 1.57 $kg.m^{-2}$) than female university runners in this study (20.09 ± 1.75 $kg.m^{-2}$). Similarly, Sedano *et al.* (2009:390) noted a lower mean BMI of 22.26 ± 1.60 $kg.m^{-2}$ for elite Spanish National First Division soccer players compared to this study (22.49 ± 1.50 $kg.m^{-2}$). Attlee *et al.* (2017:148) reported a significantly higher mean BMI of 27.5 ± 0.8 kg.m^{-2} in United Arab Emirates female university tennis players, compared to this study, with 22.59 ± 1.14 kg.m^{-2} for university tennis players.

To conclude, the BF% and BMI values of female university athletes in this study correspond closely with those found in national and international female university athletes. However, according to the World Health Organisation, Attlee *et al*. (2017:148) indicated that for tennis the mean BF% and BMI were significantly higher than this study and compared to the other sports who were found to be in the normal BMI category. The findings of this study provide possible answers to the questions of whether anthropometric profiles of elite athletes differ depending on player position, type of sport, as well as level of play.

5.3 CORE STRENGTH

It is expected that an elite athlete will have the necessary core strength to optimise athletic performance. Wahl and Behm (2008:1360) stated that resistance exercises that emphasise core musculature are frequently used to enhance overall strength, balance and flexibility; as well as to increase spinal stabilisation. In conjunction with these sports performance variables, athletes competing at an elite level require better core strength than non-athletes, depending on their sport and position played. As described by Saeterbakken *et al*. (2015:56), core strength was assessed using the Bering-Sorensen tests which included the IBE test, LF test and the AF test. The current study reports the IBE, LF and AF characteristics of core strength in female university athletes and found that, overall, there is a statistically significant difference between sports with respect to all three characteristics of core strength (Table 4.7). These results provide possible answers for questions regarding the different components of core strength and, subsequently, the different functions (i.e. lumbar extension, flexion, and lateral flexion) of the core muscles.

5.3.1 Isometric Back Extension Characteristic

This study reports a mean IBE core strength for female university athletes of 1 002.47 ± 206.31N, which varies from a minimum of 687.00N for netball to a maximum of 1 517.00N for both netball and soccer (Table 4.8). The mean IBE value of core strength of hockey (1 056.58 ± 208.46N) was the highest and tennis (782.64 ± 34.03N) the lowest. Netball (1 036.75 ± 209.89N), runners (1 024.07 ± 191.12N) and soccer (1 017.00 ± 205.48N) do not show much variation in IBE core strength. Furthermore, hockey, netball, running and soccer do not show statistically significant differences from each other with regard to the IBE characteristic of core strength, but tennis does show a statistically significant difference from hockey, netball, running and soccer (Table 4.9).

To the researcher's knowledge, this is the first study to determine the relationship of core strength with various sports using a battery of tests to assess the different components of core strength (IBE, LF and AF). Saeterbakken *et al*. (2015:56) used these same tests to compare the relationship between core strength and core endurance by examining the muscle activation with electromyography assessment, but not with different sport codes. Existing research investigated the relationship between core stability and athletic performance using variations of these tests to assess core stability (back extension, trunk flexion and lateral flexion) (Stanton *et al*., 2004:526; Tse *et al.,* 2005:549; Cowley & Swensen, 2008:620; Nesser *et al*., 2008:1753; Nesser & Lee, 2009:24; McGill, 2010:40) and various athletic performance tests, including vertical jump, 20 m and 40 m sprint and 10 m shuttle run, 5000 m run, VO_2max, broad jump, medicine ball throw and 2000 m maximal rowing ergometer test, but did not compare different sport codes.

5.3.2 Lateral Flexion Characteristic

The current study reports a mean LF core strength for female university athletes of 799.04 ± 141.26N. Hockey showed the highest mean LF core strength of 857.83 ± 149.97N and tennis the lowest with 667.09 ± 28.21N (Table 4.8). Netball (799.44 ± 113.04N), runners (772.53 ± 153.61N) and soccer (824.41 ± 135.34N) do not show much variation in LF core strength. Furthermore, this study also found that hockey, netball, running and soccer do not show statistically significant differences from each other with regard to the LF characteristic of core strength, but tennis shows statistically significant differences from hockey, netball, running and soccer (Table 4.9). As mentioned earlier, no other research has been conducted in this regard to enable any comparisons.

5.3.3 Abdominal Flexion Characteristic

This study demonstrates a mean AF core strength of 897.22 ± 162.34N for female university athletes, which varies from a minimum of 646.00N for hockey to a maximum of 1 300.00N for netball (Table 4.8). The mean AF core strength of hockey (958.25 ± 175.43) was the highest and tennis (735.65 ± 23.18N) the lowest. Netball (905.56 ± 130.37N), runners (859.00 ± 157.48N) and soccer (941.47 ± 160.61N) do not show much variation in AF core strength. Furthermore, this study also reported that hockey, soccer and netball do not show statistically significant differences from each other with regard to the AF characteristic of core strength. Similarly, soccer, netball and running do not show statistically significant differences from each other, but hockey shows statistically significant differences from running and tennis which shows statistically significant differences from hockey, soccer, netball and running (Table 4.9).

To conclude, in this study hockey demonstrates the highest IBE, LF and AF characteristics of core strength and tennis the lowest. This can be attributed to the fact that the body position of a hockey player is always flexed at the lumbar spine, with combined rotational movements that require good core strength during various hitting and pushing techniques (Clarke, 2009:4). Zingaro (2018:18) has proposed that the core and upper extremity muscles are responsible for 54% of force production when serving in tennis serve. Moreover, it has been found that the speed of shoulder movement when serving can be up to 76 kilometres an hour. This could conclude that most of a serve's explosive power in tennis players originates from the shoulder, and not the core. Despite inconsistent findings, researchers are of the opinion that different sport codes require different functions of core strength.

5.4 CORE ENDURANCE

Bliss and Teeple (2005:179) reported that athletes require good core muscular endurance to enable the spine to control movement beyond the neutral position over a time period when executing athletic and functional activities. Fatigue in novice runners revealed changes in the trunk and trunk kinematics which could be indicative of poor core endurance (Koblbauer *et al.*, 2014:420). Consequently, athletes require good core endurance to compete at an elite level in their sport and position. Due to core strength and endurance being assessed using the Bering-Sorensen tests, including the IBE, LF and AF tests, this study reports the IBE, LF and AF characteristics of core endurance in female university athletes and found that overall sports show statistically significant differences with respect to all three characteristics of core endurance (Table 4.11). It is clear that the major differences in core endurance reflect that the function of the core, and specifically the endurance component, depends on the sport code.

5.4.1 Isometric Back Extension Characteristic

This study reports a mean IBE core endurance of 149.74 ± 58.42 s for female university athletes, which varies from a minimum of 50.00 s for hockey to a maximum of 364.00 s for runners (Table 4.14). The mean IBE value of core endurance of runners (198.80 ± 77.95 s) was the highest and netball (97.75 ± 36.36 s) the lowest. Hockey (143.92 ± 47.95 s), soccer (140.18 ± 36.03 s) and tennis (185.91 ± 22.73 s) do not show much variation in IBE core endurance. Furthermore, this study found that running and tennis do not show statistically significant differences from each other with regard to the IBE characteristic of core endurance, but hockey, soccer and netball show statistically significant differences from running and tennis (Table 4.13). Similarly, hockey and soccer do not show statistically significant differences from each other, but running, tennis and netball do show statistically significant differences from hockey and soccer (Table 4.13). Thus, netball shows statistically significant differences from hockey, running, soccer and tennis (Table 4.13). The latter could possibly be due the fact that netball does not demand endurance in the extension of the back, as it demands explosive power rather than endurance.

5.4.2 Lateral Flexion Characteristic

The current study reports a mean LF value of core endurance of 67.62 ± 33.07 s for female university athletes. Runners showed the highest mean LF core endurance of 90.97 ± 33.29 s and netball the lowest with 44.99 ± 39.92 s (Table 4.14). Hockey (71.18 ± 29.20 s), soccer (62.81 ± 20.94 s) and tennis (68.35 ± 25.62 s) do not show much variation in LF core endurance. This study also found that running, hockey and tennis do not show statistically significant differences from each other. Similarly, hockey, tennis and soccer do not show statistically significant differences from each other as well as tennis, soccer and netball which do not show statistically significant differences from each other, but running shows a statistically significant difference from soccer and netball and hockey differs with statistical significance from netball (Table 4.13). These findings support the hypothesis in the sport sector that different sport codes demand different components of the core and should be considered separately when being assessed and trained.

5.4.3 Abdominal Flexion Characteristic

This study demonstrates a mean AF value of core endurance of 149.16 ± 70.09 s for female university athletes, which varies from a minimum of 40.00 s for netball to a maximum of 376.00 s for runners (Table 4.14). The mean AF core endurance for runners (203.67 ± 88.95 s) was the highest and netball (101.26 ± 66.92 s) the lowest. Hockey (157.96 ± 63.23), soccer (135.24 ± 47.64 s) and tennis (146.82 ± 31.83 s) do not show much variation in AF core endurance. Furthermore, this study reported that hockey, tennis and soccer do not show statistically significant differences from each other with regard to the AF characteristic of core endurance and tennis, soccer and netball do not show statistically significant differences from each other (Table 4.13), but running, hockey and netball do show statistically significant differences from each other and running shows a statistically significant difference from hockey, tennis, soccer and netball (Table 4.13).

To conclude, this study shows that runners have the highest IBE, LF and AF characteristics of core endurance and netball the lowest. Tong *et al*. (2014:244) noted that core muscle fatigue may limit running endurance. Clark *et al.* (2017:2289) reported that improved core endurance decreased overall running times in high school cross-country runners. This study corresponds with previous literature (Tong *et al.*, 2014:244; Clark *et al.*, 2017:2289) that runners require core endurance for improved athletic performance, as a positive correlation was found. Optimal performance in netball depends on the collaboration of several fundamental factors relating to the balance, agility and explosive power of players (Ferreira & Spamer, 2010:58). Hence, muscle endurance is not the most relevant component in training interventions for netball players. In addition, netball players depend on quadriceps' eccentric strength more when cutting and landing rather than the core musculature (Venter *et al.*, 2017:190). As it can be seen in this study, this explains why netball showed the lowest mean values for core endurance.

5.5 CORE MOTOR CONTROL

Comerford and Mottram (2001:16-17) stated that the CNS is responsible for the activation of the protective feed-forward mechanism of lower extremity movement, as is needed in sports. Core motor control assists with proper lower extremity kinematics during movement. A study by Hart *et al.* (2009:461) evaluated various lower extremity adaptations in jogging kinetics after fatiguing the lumbar paraspinal muscles and concluded that motor control of the core musculature is important in elite athletes. This study reports the core motor control characteristic of female university athletes, as was assessed using the Wisbey-Roth Core Stability Grading System, and found that overall sports differ with statistical significance with respect to core motor control (Table 4.15).

This study noted that 37.35% of female university athletes obtained a grade 3 on the Wisbey-Roth Core Stability Grading System, followed by grade 4 (25.30%), grade 2 (20.48%), grade 1 (15.66%) and grade 5 (1.20%) (Table 4.20). Netball (56.25%) reported the highest percentage of grade 1 core motor control and runners (0.00%) and tennis (0.00%) both the lowest. The highest percentage of a grade 2 core motor control was noted in soccer (35.29%) and the lowest in tennis (9.09%), whilst tennis (63.64%) showed the highest percentage of a grade 3 core motor control in this study and netball (6.25%) the lowest. The highest percentage of a grade 4 core motor control was obtained by runners (40.00%) and the lowest by netball (6.25%), whilst only one runner (6.67%) obtained a grade 5 on the Wisbey-Roth Core Stability Grading System. Furthermore, this study found that running, tennis and hockey do not show statistically significant differences from each other with regard to core motor control as well as tennis, hockey and soccer which do not show a statistically significant difference from each other. However, running, soccer and netball do show statistically significant differences from each other and netball shows statistically significant differences from running, tennis, hockey and soccer (Table 4.17). These significant differences could possibly reflect the differences in training programmes based on the different demands of sport codes.

To conclude, core motor control performance of each athlete may vary within a team and depends on the sport and position played. This study demonstrated that netball has less core motor control (grade 1) than tennis (grade 3) and runners (grade 4). As previously mentioned, Venter *et al*. (2017:190) reported that netball players rely more on lower extremity strength for cutting and landing movements than the core musculature, whereas runners require proximal stability to handle much greater, repetitive and gravitational loads (Comerford & Mottram, 2001:23).

As can be seen in this study, contrary views remain on the significance of core stability in sporting performance and no studies reviewed for this research used a battery of tests to assess the different components of core stability (strength, endurance and motor control) as well as the relationship with different sports (hockey, netball, runners, soccer and tennis), therefore no comparisons could be made in this regard.

5.6 ATHLETIC PERFORMANCE

It is expected for athletes to be explosive at any given moment and to constantly transfer forces between the upper and lower extremities which require support from the core musculature to maintain the kinetic chain of the body. Sharrock *et al.* (2011:70) found moderate to high (r=0.3-0.7) correlations with athletic performance in female athletes, similar to the findings of Nesser and Lee (2009:25). This study reports the athletic performance, as assessed by means of the 40 m sprint, T-Test, vertical jump and medicine ball chest throw, of female university athletes and found that overall sports show a statistically significant difference with respect to all four athletic performance characteristics (Table 4.19). These results support the opinion of researchers that sport codes relate differently to athletic performance based on the demands of the respective sports.

5.6.1 40 m Sprint

Many sport types require fast speed; therefore, speed is important to excel at the highest levels. This study used the 40 m sprint to determine the speed of female university athletes and reported an overall mean value of 6.40 ± 0.40 s (Table 4.26), which is lower than the mean values of 6.44 ± 0.74 s reported by Loubser (2018:78). The mean values of female university athletes for the 40 m sprint are reported by Allah and Nagi (2013:7) as 6.11 ± 0.53 s. In this current study, runners demonstrated the fastest sprint time of 5.73 s and hockey (7.87 s) the slowest. The mean 40 m sprint time of runners (6.10 ± 0.28 s) was the fastest and netball (6.58 ± 0.36 s) the slowest. Hockey (6.35 ± 0.43 s), soccer (6.47 ± 0.41 s) and tennis (6.54 ± 0.29 s) do not show much variation in sprinting time. Furthermore, this study found that netball, tennis, soccer and hockey do not show statistically significant differences from each other with regard to the 40 m sprint, but running shows statistically significant differences from netball, tennis, soccer and hockey (Table 4.21). These results could be attributed to the fact that runners are more conditioned with regard to the 40 m sprint as the latter also includes straight line running.

Nuell *et al*. (2019:1) reported higher mean values for runners of the 40 m sprint (6.12 ± 0.15 s) in female national-level sprinters, compared to this study. To date, no research has been conducted on the 40 m sprint times of elite female netball players. However, this study showed lower mean values for the 40 m sprint than the national standard of the New Zealand netball team, with a norm value of 6.95 s. By comparison, Loubser (2018:78) found female University of the Free State hockey (6.22 ± 0.60 s) and soccer (5.40 ± 0.20 s) players to be faster than female university hockey and soccer players in this study. In tennis, it is rare that a player has to travel more than 10-15 m. This could possibly be the reason that, to date, no studies have determined the mean 40 m sprint time of elite tennis players for comparison with this study.

To conclude, female university athletes in this research show faster 40 m sprinting times for runners and netball and slower for hockey and soccer, compared to national and international elite female athletes. This can be attributed to the fact that the 40 m sprint is not the best sport-specific test for hockey and soccer. These two sport codes demand shorter bursts over a shorter distance. On the other hand, runners are used to running distances of 40 m or more during training and therefor performed better in the 40 m sprint than the other four sport codes.

5.6.2 T-Test

Improvement in direction change and the ability to accelerate from a stationary position to maximal speed is important in every sport code. With regard to agility, the female athletes of this study recorded a mean time of 12.70 s for the T-Test (Table 4.20), which is slower than the mean time of 12.01 s reported by Loubser (2018:78). In this study, tennis showed the highest mean T-Test time of 13.42 s and runners the lowest with 12.24 s. Hockey (12.29 s), netball (12.73 s) and soccer (12.76 s) do not show much variation in the T-Test times. This study also found that, for the T-test, soccer, running, netball and hockey do not show statistically significant differences from each other, but tennis shows statistically significant differences from soccer, running, netball and hockey (Table 4.21). It is clear that this significant difference is due to the fact that tennis, when compared to the other four sports, performed the best in the T-test.

Sood (2013:31) reported that the time in seconds for competitive female university tennis players to complete the T-Test is 10.69 ± 1.18 s, which is faster compared to this study (13.42 ± 0.36 s). Reiman and Manske (2009:202), reported T-test values of 10.8 s for competitive female university runners, compared to this study with 12.24 ± 0.77 s for female university athletes. Loubser (2018:78) noted faster T-Test times in female university athletes with mean values of 11.81 ± 0.58 s for hockey and 12.13 ± 0.59 s for soccer, compared to this study with 12.29 ± 0.73 s and 12.76 ± 0.79 s for female university hockey and soccer athletes, respectively. According to the researcher's knowledge, there are various agility performance tests that have been established according to the demand of different sport codes which emphasise the change of direction speed. Barber *et al*. (2015:379) declared that the 5-0-5 agility test has been shown to yield the best reliable assessment of change of direction amongst female netball players, with a high test-retest reliability (ICC = 0.96-0.97). Consequently, no studies reviewed by the researcher used the T-Test to assess agility performance in female netball players.

To conclude, female university athletes in this study demonstrate slower T-Test times for hockey, runners, soccer and tennis, compared to national and international female university athletes. As mentioned previously, trainers and coaches should focus on the demand of the sport in order to condition athletes optimally. This study's results could possibly be due to a lack of agility training in the conditioning programmes of these sport codes.

5.6.3 Vertical Jump

Several sports, such as netball, soccer and tennis, demand explosive power of the legs to jump from the surface area to a maximum height (Sharrock *et al.*, 2011:69). These high intensity jumps require high anaerobic capacity. This study used the vertical jump to determine lower extremity explosive power. The mean vertical jump score recorded for female university athletes was 43.49 ± 4.94 cm (Table 4.26), which is higher than the reported vertical jump heights of 41.33 ± 8.27 cm for female university athletes (Loubser 2018:78). This study shows that runners had the highest mean vertical jump of 45.67 cm and tennis the lowest with 37.00 cm. Hockey (45.47 cm), netball (44.56 cm) and soccer (41.88 cm) do not show much variation in vertical jump heights. Furthermore, this study found that hockey, running and netball do not show statistically significant differences from each other with regard to the vertical jump (Table 4.21). Similarly, netball and soccer do not show statistically significant differences from each other, but soccer shows statistically significant differences from hockey and tennis, respectively, and tennis shows statistically significant differences from hockey, running, netball and soccer (Table 4.21). The latter result could be attributed to the fact that, coaches do not focus on this variable in their conditioning programmes.

Singh *et al.* (2019:1464) reported a mean vertical jump height of 38.00 ± 0.07 cm in female university level runners, which is much lower in comparison with a mean vertical jump height of 45.67 ± 5.38 cm for female university runners in this study. By comparison, Suna and Kumartasli (2017:116) found the vertical jump height (55.40 ± 5.5 cm) in female university tennis players to be much higher than female university tennis players in this study (37.00 ± 2.72 cm). Loubser (2018:78) noted lower vertical jump heights in female university athletes with mean values of 45.15 ± 5.93 cm for hockey and 38.65 ± 5.56 cm for soccer, compared to this study with 45.47 ± 3.81 cm and 41.88 ± 3.26 cm for female university hockey and soccer athletes, respectively. This study showed lower mean values for the vertical jump for netball (44.56 ± 4.49 cm) than the national standard of the New Zealand netball team, with a norm value of 65 cm (Netball New Zealand, 2020).

To conclude, female university athletes in this study demonstrate higher vertical jump heights for hockey and soccer and lower for runners, netball and tennis, compared to national and international elite female and university athletes. This could be due to differences in the training programmes of each type of sport.

5.6.4 Medicine Ball Chest Throw

Upper extremity explosive power is considered as another important modality for athletic performance in sports involving a throwing or hitting mechanism, such as hockey, netball, soccer and tennis. This study used the medicine ball chest throw to determine upper extremity explosive power of female university athletes and reported a mean distance of 4.32 ± 0.48 m. Loubser (2018:78) noted a lower mean distance of 3.42 ± 0.65 m for female university athletes. The mean values in this study vary from a minimum of 3.48 m for hockey, soccer and tennis, respectively, to a maximum of 5.95 m for runners. Hockey recorded the highest mean distance of 4.45 m and tennis the lowest with 3.88 m. Netball (4.35 m), runners (4.44 m) and soccer (4.27 m) do not show much variation in medicine ball chest throw distances. This study also found that, for the medicine ball chest throw, soccer, running, netball and hockey do not show statistically significant differences from each other, but tennis shows statistically significant differences from soccer, running, netball and hockey (Table 4.21). This finding reflects that tennis requires less upper extremity explosive power than soccer, running, netball and hockey or that the conditioning programme of tennis does not focus enough on upper extremity explosive power.

Loubser (2018:78) found a much lower mean distance for female university hockey players (3.64 ± 0.56 m) compared to this study with 4.45 ± 0.49 m. Filipcic and Filipcic (2005:168) reported a mean medicine ball chest throw distance of 5.78 ± 7.7 m in young female tennis players, which is higher than the female university tennis players in this study with 3.88 ± 0.35 m. Venter *et al*. (2005:3) highlighted the importance of comprehensive studies to conduct research on normative data for elite levels of netball players. To date, normative values for the medicine ball chest throw in netball players have not been investigated. Upper extremity explosive power is considered as a less important modality in runners and therefore no studies reviewed by the researcher used the medicine ball chest throw to determine upper extremity explosive power in female runners. Loubser (2018:78) reported a mean throwing distance of 3.00 ± 0.41 m for female university soccer players, which is lower than this study (4.27 ± 0.38 m) for female university soccer players.

To conclude, female university athletes in this study show a higher medicine ball chest throw mean for hockey and soccer and lower for tennis, compared to national and international female university athletes. These results were expected as both hockey and soccer require upper extremity explosive power for hitting and throwing performances, respectively, whereas the result of lower upper extremity explosive power in tennis players was not as expected as the serve in tennis demands a great amount of explosive power originating from the upper extremities (Zingaro, 2018:18). This study succeeded in showing that there are significant differences in core stability and athletic performance when the different sport codes are considered separately.

5.7 ASSOCIATION BETWEEN CORE STRENGTH AND ATHLETIC PERFORMANCE

Table 5.1 displays a summary of the strength of correlation between the three characteristics of core strength and the four characteristics of athletic performance, overall and by type of sport. Note that only correlations above 0.5 (or below -0.5), that is, only "moderately strong" or "strong" correlations are highlighted.

Table 5.1: Strength[a] of correlation between characteristics of core strength and of athletic performance: Overall and by type of sport

Sport	Characteristic of core strength	Speed (40 m Sprint)	Agility (T-Test)	Explosive power (Vertical Jump)	Explosive power (Chest Throw)
All sports	**LF**			Strong	Moderately strong
Hockey	**IBE**				Moderately strong
	LF		Moderately strong		Moderately strong
	AF				Moderately strong
Netball	**LF**	Moderately strong	Moderately strong	Moderately strong	
Runner	**LF**			Moderately strong	Moderately strong
	AF		Moderately strong	Moderately strong	Moderately strong
Soccer	**IBE**		Moderately strong	Moderately strong	Moderately strong
	LF			Moderately strong	Moderately strong

	AF		Moderately strong	Moderately strong	Moderately strong
Tennis	**IBE**	Moderately strong	Moderately strong		Moderately strong
	LF	Moderately strong			Moderately strong
	AF	Moderately strong			

[a]Strength of correlation was categorised as moderately strong if r=0.5-0.8 or strong if r=0.8-1.0. Only correlations larger than 0.5 ("moderately strong" or "strong") are displayed in the table.

5.7.1 Overall: Strength of correlation between characteristics of core strength and athletic performance

As Table 5.1 shows, overall for all sports, only the LF characteristic of core strength is important for upper extremity and lower extremity explosive power performance. None of the core strength characteristics are associated with speed and agility performance.

5.7.2 Hockey: Strength of correlation between characteristics of core strength and athletic performance

The strength of correlation in Table 5.1 suggests that, for hockey, IBE, LF and AF seem to be important for upper extremity explosive power performance, and only LF for agility performance. The results also show that none of the core strength characteristics are important for speed and lower extremity explosive power performance.

5.7.3 Netball: Strength of correlation between characteristics of core strength and athletic performance

For netball, Table 5.1 shows that only LF is associated with athletic performance, and specifically with speed, agility and lower extremity explosive power performance. None of the core strength characteristics are associated with upper extremity explosive power performance.

5.7.4 Runner: Strength of correlation between characteristics of core strength and athletic performance

The results suggest that, for runners, LF and AF are important for upper extremity and lower extremity explosive power performance, and only AF for agility performance. None of the core strength characteristics seem to be important for speed performance.

5.7.5 Soccer: Strength of correlation between characteristics of core strength and athletic performance

For soccer, Table 5.1 shows that IBE, LF and AF seem to be important for upper extremity and lower extremity explosive power performance, and IBE and AF for agility performance. It can also be seen that none of the core strength characteristics seem to be important for speed performance in soccer.

5.7.6 Tennis: Strength of correlation between characteristics of core strength and athletic performance

The results suggest that, for tennis, IBE, LF and AF are important for speed performance, and IBE and LF for upper extremity explosive power performance. Only IBE seems to be important for agility performance, whereas none of the core strength characteristics are associated with lower extremity explosive power performance.

5.8 CORE ENDURANCE AND ATHLETIC PERFORMANCE

Table 5.2 displays a summary of the strength of correlation between the three characteristics of core endurance and the four characteristics of athletic performance, overall and by type of sport. Note that only correlations above 0.5 (or below -0.5), that is, only “moderately strong” or “strong” correlations are highlighted.

Table 5.2: Strength[a] of correlation between characteristics of core endurance and of athletic performance: Overall and by type of sport

Sport	Characteristic of core endurance	Speed (40 m Sprint)	Agility (T-Test)	Explosive power (Vertical Jump)	Explosive power (Chest Throw)
Runner	**AF**			Moderately strong	
Tennis	**IBE**	Moderately strong			
	LF				Moderately strong

[a]Strength of correlation was categorised as moderately strong if r=0.5-0.8 or strong if r=0.8-1.0. Only correlations larger than 0.5 (“moderately strong” or “strong”) are displayed in the table.

5.8.1 Runner: Strength of correlation between characteristics of core endurance and athletic performance

Table 5.2 summarises that, for runners, only AF is important for lower extremity explosive power performance. None of the characteristics of core endurance are associated with speed, agility and upper extremity explosive power performance.

5.8.2 Tennis: Strength of correlation between characteristics of core endurance and athletic performance

For tennis, the results suggest that IBE seems to be important for speed performance and LF for upper extremity explosive power performance. None of the characteristics of core endurance are important for agility and lower extremity explosive power performance.

5.9 CORE MOTOR CONTROL AND ATHLETIC PERFORMANCE

Table 5.3 displays a summary of the strength of correlation between core motor control and the four characteristics of athletic performance, overall and by type of sport. Note that only correlations above 0.5 (or below -0.5), that is, only “moderately strong” or “strong” correlations are highlighted.

Table 5.3: Strength[a] of correlation between core motor control and of athletic performance: Overall and by type of sport

Sport	Speed (40 m Sprint)	Agility (T-Test)	Explosive power (Vertical Jump)	Explosive power (Chest Throw)
Soccer	Moderately strong	Moderately strong		

[a]Strength of correlation was categorised as moderately strong if r=0.5-0.8 or strong if r=0.8-1.0. Only correlations larger than 0.5 (“moderately strong” or “strong”) are displayed in the table.

5.9.1 Soccer: Strength of correlation between core motor control and athletic performance

As Table 5.3 shows, soccer was the only sport to reveal that core motor control is important for speed and agility performance. The results also suggest that core motor control is not associated with upper extremity and lower extremity explosive power performance.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 INTRODUCTION

Knowledge of core stability during conditioning training and rehabilitation is important in both the sport and rehabilitation sectors for effective planning of exercise training programmes in preparation of optimal athletic performance. Therefore, the primary objective of this research study was to establish an anthropometric and physical profile of hockey, netball, runners, soccer and tennis female university athletes and to determine whether a relationship exists between core stability and athletic performance. Hibbs *et al*. (2008:996) concluded that a better understanding of the different roles that muscles have when training core stability would lead to the design of more functional and sport-specific exercise training programmes. Consequently, the transfer of sport-specific skills will be more effective in the improvement of actual sport techniques and performance. For this reason, this research study will assist coaches, conditioning staff and rehabilitation specialists with updated information on core stability for the development of conditioning and rehabilitation programmes in different sport codes.

This chapter will discuss the trends in the analysed data and conclude the findings of this research study. Further suggestions regarding core stability training programmes and athletic performance will also be discussed.

6.2 SUMMARY

The question answered in this research study was if core stability and athletic performance are associated with each other. The findings of this research study provide results in order to answer this question and can be used in scientific literature as well as implemented in sport and rehabilitation sectors to improve the athletic performance of elite athletes.

To date, core stability has been considered as one component in the sport and rehabilitation sectors, both in the testing protocols and training programmes. Many studies have investigated the relationship between core stability and athletic performance and found conflicting results. Consequently, the development of conditioning and rehabilitation programmes remains a challenge due to insufficient knowledge on the effect of core stability to improve athletic performance. This research study highlights the role of the different components of core stability (core strength, core endurance and core motor control) and the effect of each component on athletic performance, but because of many factors playing a role in athletic performance, it remains a challenge to summarise the benefits of core stability training on athletic performance. Since core stability training is always combined with other exercise modalities (hypertrophy, strength, endurance, explosive power, agility and speed), it is not justified to conclude that core stability is the main component for optimal athletic performance even if significant correlations between core stability and athletic performance are found. Furthermore, it is also difficult to measure each of the components of core stability, as there is no gold standard test. However, the findings of this research study may highlight areas of uncertainty that exist in the sport and rehabilitation sectors among athletes, coaches, conditioning staff and rehabilitation specialists.

Few literature studies have observed the improvement in athletic performance in different sport codes despite observing core stability improvements after core stability training interventions (Hibbs *et al*., 2008:995). Based on the results of this study, it is evident that all three components of core stability (core strength, core endurance and core motor control) reported weak correlations to most athletic performance measures, with only significant correlations within certain sport codes.

6.3 CONCLUSION

This study depicts the anthropometric profiles of female university athletes and found that runners have the greatest height compared to hockey, netball, soccer and tennis, and netball the highest body weight, BF% and BMI compared to hockey, runners, soccer and tennis. Hockey, soccer and tennis players' height and body weight in this study exceeded those reported in national and international female university athletes, whereas netball players and runners reported lower height and body weight values in this study when compared to national and international female university athletes. BF% and BMI values in this study correspond closely with those found in national and international female university athletes. All sport codes in this study were found to be in the normal BMI category. This study also found that overall sports show statistically significant differences with respect to age, body weight, BF% and BMI, but height does not show statistically significant differences between sports.

This research study reveals that hockey had the highest mean value for core strength and tennis the lowest, as measured by the IBE, LF and AF characteristics. With regard to core endurance, this research study found that runners had the highest mean value and tennis the lowest, as measured by the same characteristics as core strength, only for time. The highest value of core motor control was noted in runners (grade 5) and the lowest, as reported by average, in netball (grade 1). The highest average percentage of female university athletes obtained a grade 3. Furthermore, this study found that that, overall, sports show statistically significant differences with respect to all three characteristics of core strength and core endurance as well as the core motor control component.

When considering the correlations between core stability and athletic performance, this research study found that, for all sport codes, all correlations of core strength, core endurance and core motor control with athletic performance were weak (r<0.2) or moderately weak (r=0.2-0.5). However, when the different core tests were considered separately, the correlations for the LF characteristic of core strength were moderately strong (r=0.5-0.8) for the medicine ball chest throw and strong (r=0.8-1.0) for the vertical jump. The results of this research study show that only core strength is important for explosive power (medicine ball chest throw and vertical jump) performance.

When considered by the different sport codes separately, moderately strong correlations were found in all sport codes in the different core strength characteristics with certain athletic performance tests. Regarding the various sport codes, this study found that the different characteristics of core strength correlate with:

- Hockey: all three characteristics for upper extremity explosive power (medicine ball chest throw) performance and LF characteristic for agility (T-test) performance.
- Netball: LF characteristic for speed (40 m sprint), agility (T-test) and lower extremity explosive power (vertical jump) performance.

- Runner: LF and AF characteristics for upper and lower extremity explosive power (medicine ball chest throw and vertical jump) performance and AF characteristic for agility (T-test) performance.
- Soccer: IBE and AF characteristics for agility (T-test) performance, and IBE, LF and AF characteristics for upper and lower extremity (medicine ball chest throw and vertical jump) performance.
- Tennis: all three characteristics for speed (40 m sprint) performance, IBE characteristic for agility (T-test) performance, and IBE and LF characteristics for upper extremity explosive power performance.

Furthermore, for runners, the AF characteristic of core endurance correlate with lower extremity explosive power (vertical jump) performance, and, for tennis, it was found that IBE characteristic of core endurance is important for speed (40 m sprint) performance, and LF for upper extremity explosive power (medicine ball chest throw) performance and,. Lastly, soccer was the only sport to reveal that core motor control is important for speed (40 m sprint) and agility (T-test) performance. In conclusion, this study found that overall sports show statistically significant differences with respect to all four athletic performance characteristics.

This research study has provided an initial insight into the importance of core stability training in the different sport codes. Based on the results of this research study, the different characteristics of core strength and core endurance, as well as the core motor control component, should be trained for:

- Hockey: all three characteristics of core strength by executing core exercises against resistance in a supine, prone and lateral position.
- Netball: LF characteristic of core strength through means of core exercises against resistance in a lateral position.
- Runner: LF and AF characteristics of core strength by performing core exercises against resistance in a supine and lateral position as well as in a supine position for a duration of time in order to target core endurance.
- Soccer: all three characteristics of core strength by executing core exercises against resistance in a supine, prone and lateral position and core stabilisation

exercises, keeping the pelvis and spine stable, in a supine position in order to target the core motor control component.

- Tennis: all three characteristics of core strength by performing core exercises against resistance in a supine, prone and lateral position as well as in a supine and lateral position for a duration of time in order to focus on the core endurance component.

The practical implication of this research study is that core stability training should be part of training programmes. Two factors need to be considered when core stability is assessed and training programmes are designed:

(1) Core stability classification according to core strength, core endurance and core motor control is necessary to reveal precise representative data for each specific component.
(2) Training programmes should include the different components of core stability and the relevance of each component to the different sport codes in order to improve athletic performance of elite athletes based on their sport and position played.

In conclusion, this research study found correlations between core stability and athletic performance, even though many correlations were weak or moderately weak. It can also be concluded that different sport codes require different components of core stability, as well as have different sets of skills based on the position played and event (runners). Therefore, core stability can be considered as an important modality to improve athletic performance, however, it should not be the main focus in exercise training programmes. The findings of this research study will equip athletes, coaches, conditioning staff and rehabilitation specialists to better design exercise training programmes by implementing sport-specific modalities into programmes that duplicate the demands of the respective sport codes.

6.4 LIMITATIONS AND FUTURE RESEARCH

The following limitations of this research study should be noted and may be proof for relevant topics for future research:

- Only five sport codes of the University of the Free State were examined. These sport codes' specific techniques and skills might not be representative of all sport codes in the sport sector.
- Only female athletes of the University of the Free State were used. Male athletes may report different results than female athletes. Other universities may use different conditioning programmes that may have an influence on the results.
- The population of this research study might have impacted the results of the data, due to athletes being assessed during different times in the conditioning season.
- The differences in conditioning training programmes might have influenced the results. Different sport codes focus on different exercise modalities, resulting in different exercise training programmes that might not even have included core stability training.
- The lack of gold standard tests to assess core strength, core endurance and core motor control components of core stability. Sport-specific assessments should be considered to assess core stability.
- The athletic performance tests did not account for the specific demands of the different sport codes. More sport-specific assessments of athletic performance may have an influence on the results.

Core stability and athletic performance are two complex concepts, with multiple factors playing a role in both. Future research on core stability and athletic performance, with specificity to the demands of different sport codes, would benefit both the sport and rehabilitation sectors.

CHAPTER 7

REFLECTING ON THE RESEARCH PROCESS

7.1 INTRODUCTION

As a Biokineticist, I am constantly searching for new research and exercises to improve my rehabilitation programmes and the performance of my athletes. The multi-faceted nature of Biokinetics makes research in the field challenging and broad. Knowledge of the profession, years of experience, achieving patient expectations and clinical reasoning can lead to a good and successful Biokineticist.

Henry Ford said, "Nothing is particularly hard if you divide it into small jobs". At the end, research is all about hours of planning and dedication to get to the final product. It is a process of learning, making mistakes, exploring new information and gaining knowledge. Research requires an unshakable will and perseverance. I became demotivated and wanted to give up numerous times, but my will to succeed and perseverance helped me get to the end. I have learned about my strengths and weaknesses and to not rely only on my own knowledge and understanding, but to let go of pride and ask for help.

I believe that those who do not do research, do not grow. The only way to improve yourself in a profession or specific field is to do research. The more research you do, the better you will become. Evidence-based medicine is essential for the training of clinicians by focussing on critical thoughts and clinical reasoning.

7.2 REFLECTING ON THE RESEARCH PROCESS

As a researcher, Biokineticist and lecturer, I have come to the realisation that athletes and coaches have limited understanding of what should really be done in order to perform optimally. The reasoning behind why certain exercises are important and how it will benefit the athlete long-term is lacking. Today's busy lifestyles and high expectations lead to people doing only what is necessary within a certain time. In the sport and rehabilitation sectors, the same applies. During training, athletes and coaches spend time on the exercises that will change the score board and help them achieve optimal performance. This made me think that it is time for all role players in the sport and rehabilitation sector to start focusing on what is really important. I started to question the effect of certain exercises and training programmes on athletic performance and how, and if, these exercises and training programmes actually contribute to athletes' performance. Core stability is a commonly used concept in both the sport and rehabilitation sectors and I believe that this research study considered the finest details in order to make recommendations to athletes, coaches, conditioning staff and rehabilitation specialists.

This research study will add value to my work as a Biokineticist and lecturer, as well as to my personal understanding of research and ways of thinking. I am motivated to never stop doing research and to constantly improve myself in every aspect of life.

7.3 PERSONAL REMARKS

This was a stressful and exhausting journey, but what I have learned through the process can never be taken away from me. I am thankful for my support system that enabled me to complete this research project. My parents, Theuns and Erina de Bruin, my sister, Elizma de Bruin, and my boyfriend, James Moore, were my biggest supporters and motivated me from beginning to end. My friends also played a tremendous role in encouraging me to not give up and persevere to the end.

My supervisor, Prof Derik Coetzee, and co-supervisor, Dr Marlene Opperman, added irreplaceable value to my research project. Their knowledge and experience in the fields of research and Biokinetics is exceptional. I was privileged to work with them, both as supervisors and mentors. I am also thankful to the statistician, Prof Robert Schall, who made it a breeze to write the results of this research study and unselfishly shared his experience and knowledge with me. I greatly appreciate the Biokinetics interns who assisted me in the gathering of my data. A word of gratitude to my colleagues, Karabelo Mpeko and Nelmaré Nel, for supporting me during the study.

A healthy mind, knowledge and wisdom are gifts from God. To share them with others is a gift to God. To my Heavenly Father, Saviour and Lord, Jesus Christ, be all the glory.

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APPENDICES

APPENDIX A – BIOGRAPHICAL INFORMATION

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

You have been asked to participate in a research study. Please note that by completing this questionnaire you are voluntarily agreeing to participate in this research study. Your data will be treated confidentially at all times. You may withdraw from this study at any given moment during the completion of the questionnaire. The results of the study may be published.

1.	**Participant number**	
2.	**Date**	
3.	**Telephone number**	
4.	**Age (years)**	
5.	**Gender**	
6.	**Sport**	
7.	**Position (if applicable)**	

8. Level of play:

☐ University ☐ Provincial ☐ National ☐ International

9. Previous acute injuries:

☐ Yes ☐ No

10. If yes, state:

____

11. Did you receive any treatment for injury in the last 3 months?

☐ Yes ☐ No

APPENDIX B – DATA COLLECTION SHEET

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Participant Number:

Anthropometrical measurements

Body composition			
Weight:		**Height:**	
Kg		m	
Circumferences			
Waist:		**Hip:**	
Cm		cm	
Bone breadths			
Humerus:		**Femur:**	
cm		cm	
Skinfolds			
1st Measurement		**2nd Measurement**	
Triceps:	mm	**Triceps:**	mm
Subscapularis:	mm	**Subscapularis:**	mm
Iliac crest:	mm	**Iliac crest:**	mm
Abdomen:	mm	**Abdomen:**	mm
Front thigh:	mm	**Front thigh:**	mm
Calf:	mm	**Calf:**	mm

Core Stability Tests							
Core Endurance		**Core Strength (mean force output)**				**Core Motor Control**	
IBE:	sec	**IBE:**				**Grade (0-5):**	
Abdominal:	sec	**Abdominal:**					
LF:	sec	**LF:**					

Athletic Performance Tests					
1st Measurement		**2nd Measurement**		**3rd Measurement**	
Vertical Jump:	cm	**Vertical Jump:**	cm	**Vertical Jump:**	cm
T-Test:	sec	**T-Test:**	sec	**T-Test:**	sec
Chest throw:	m	**Chest throw:**	m	**Chest throw:**	m
40m Sprint:	sec	**40m Sprint:**	sec	**40m Sprint:**	sec

APPENDIX C – INFORMATION DOCUMENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

INFORMATION DOCUMENT

CORE STABILITY AND ATHLETIC PERFORMANCE

I, Marizanne de Bruin, (a master's student in Biokinetics at the University of the Free State) will be conducting a research study concerning core stability and athletic performance.

This is a document requesting your participation in this research study. The aim of the study is to determine if better core stability relates to better athletic performance. This will be done by capturing data regarding core stability and athletic performance amongst athletes. The knowledge gained may assist sport coaches in exercise program prescription and advise sport professionals about different training modalities to enhance sport performance.

It will be expected from all participants to take part in four athletic performance tests and seven core stability tests (Appendix B). Anthropometric measurements will also be taken from each participant (Appendix B). Privacy of participants will be guaranteed with only the researcher present in the evaluation room to record the measurements. Each participant will be asked to fill in a questionnaire beforehand, containing socio-demographic information and level of sport participation (Appendix A). The tests will take approximately one hour to complete. Participants will be expected to wear sport attire. Participants that form part of the study must be registered at the University of the Free State, taking part in a first team in one of the qualified sports. Females between ages 18 and 25 may participate.

Participation is voluntary. Refusal or withdrawal from the study will involve no penalty or loss of benefit to which participants are otherwise entitled to. Your personal information will remain confidential by the researcher. No financial remuneration will be offered to participate in the study. If the results are published, this may lead to cohort identification, but all data will be presented anonymously.

The study is approved by the Health Sciences Research Ethics Committee of the University of the Free State. For any enquiries contact (051) 401 7387. Please contact Marizanne with any questions at (051) 401 7965 or debruinm@ufs.ac.za.

Thank you

APPENDIX D – INFORMED CONSENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

INFORMED CONSENT

The relationship between core stability and athletic performance

You are hereby asked to participate in a research study conducted by Marizanne de Bruin from the Exercise and Sports Science Department at the University of the Free State.

The aim of this study is to determine the correlation between core stability and athletic performance. The results will provide conditioning coaches and athletes with valuable information that can assist with the development of individualised and sport specific exercise program prescription and rehabilitation techniques to improve sport performance.

This will be done by collecting data that involves measurements of core stability and athletic performance during different functional movements. Before testing starts, information sessions will be held at each testing station to explain the procedure and the correct technique for every movement.

Unfortunately, there will be no payment for your participation in this study, but a comprehensive report of the outcomes will be issued on request.

Any information that is obtained regarding this study will remain confidential and will be disclosed only with your permission or as required by law. Anonymity will be maintained by means of allocating numbers to participants. Information will be kept by the researcher only and raw data held in files stored in a locked office. All processing of data will be protected by a computer password protector. Only the findings will be published with the strictest of confidentiality to the individual athletes.

Your participation in this research study is voluntary, and you will not be penalised or lose benefits if you refuse to participate or decide to terminate your participation.

If you agree to participate, you will be given a signed copy of this document as well as an information document, which will be a written summary of the research project.

The research study, including the above information has been verbally described to me. I understand what my involvement in the study means, and I may contact the researcher at the University of the Free State at any time. I voluntarily agree to participate in this study.

I understand that I may refuse to participate or withdraw from the study at any time without prejudice.

__________________ ____________

Signature of Participant Date

__________________ _______________

Signature of Researcher Date

APPENDIX E – PERMISSION LETTER FROM KOVSIE SPORT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

February 2019

Mr. DB Prinsloo

Director of Kovsie Sport

University of the Free State

BLOEMFONTEIN

9301

RE: RESEARCH PROJECT ON ATHLETIC PERFORMANCE AND CORE STABILITY

Miss M. de Bruin (Masters student) and the Exercise and Sport Sciences Department, University of the Free State hereby request permission to conduct research on female high performance athletes of the University of the Free State. The research will be completed in accordance with Prof. Derik Coetzee (Adjunct Professor & Head of Department: Department of Exercise and Sport Sciences).

The tests will be a service granted to these athletes to monitor their performance ensuring they are highly conditioned and well trained. The tests will be conducted by the University of the Free State, Exercise and Sport Science Department.

The aim of the research project is to determine the level of core stability and then compare it with the athletic performance and determine if these two variables have a correlation. This will be done by collecting measurements regarding the level of core stability using three tests to assess core endurance and core strength respectively and one test to measure core motor control; lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of a medicine ball chest throw; lower body speed and power, measured by the time in seconds during the 40m sprint and agility and power, measured by the time in seconds to complete a T-test.

All female sports teams of the University of the Free State will be visited where information regarding the testing will be explained. It will also provide an opportunity for athletes to volunteer as participants in the study. The information gathered from the tests will be analysed and the results will be used to develop sport enhancement programs for future athletes.

This study is beneficial for current participants, athletes, coaches and sport professionals. This study will also assist coaches, athletes and rehabilitation professionals with exercise program prescription that enhances athletic performance.

Participants will not be placed at risk and the information gathered will be handled with confidentiality by the researcher. All participants will complete an informed consent form. Participation is voluntary. Athletes may decide to not partake in the study.

If you have any questions or concerns regarding the conduction of tests you may contact the Secretariat of the HSREC, UFS on (051) 405 2812.

Your assistance in this matter will be greatly appreciated.

Please contact me with any questions: 051 401 7965 or debruinm@ufs.ac.za.

Regards

Researcher	Head of Department
Miss M. de Bruin	Prof F.F. Coetzee

Hereby I, Mr. DB. Prinsloo (Director of Kovsie Sport), grant the researcher permission to conduct the study using female high performance athletes of the University of the Free State.

Director of Kovsie Sport

Mr. DB. Prinsloo

APPENDIX F – PERMISSION GRANTED FROM ACADEMIC HEAD OF DEPARTMENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

February 2019

The Chair: Health Sciences Research Ethics Committee

Dr SM Le Grange

For Attention: Mrs M Marais

Block D, Room 104,

Francois Retief Building

Po Box 339 (G40)

Nelson Mandela Drive

Faculty of Health Sciences

University of the Free State

Bloemfontein

9300

Dr SM Le Grange

RESEARCH PROJECT: The relationship between core stability and athletic ability among female university athletes

I, Prof. Derik Coetzee (Adjunct Professor & Head of Department: Department of Exercise and Sport Sciences), hereby grant Miss M. de Bruin (Masters student) permission to conduct research on female high performance athletes of the University of the Free State. The research will be completed in accordance with myself as Head of Department: Department of Exercise and Sport Sciences and Supervisor of this study. I hereby grant Miss M. de Bruin permission to use the testing facilities of the Exercise and Sport Sciences Department at the University of the Free State.

Regards

____

Head of Department

Prof F.F. Coetzee

APPENDIX G – PERMISSION LETTER TO HSREC

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

February 2019

Health Science Research Ethics Committee

University of the Free State

BLOEMFONTEIN

9300

RE: APPROVAL FROM UFS AUTHORITIES FOR A RESEARCH PROJECT ON ATHLETIC PERFORMANCE AND CORE STABILITY

Miss M. de Bruin (Masters student) and the Exercise and Sport Sciences Department, University of the Free State hereby request permission to conduct research on female high performance athletes of the University of the Free State. The research will be completed in accordance with Prof. Derik Coetzee (Adjunct Professor & Head of Department: Department of Exercise and Sport Sciences).

The tests will be a service granted to these athletes to monitor their performance ensuring they are highly conditioned and well trained. The tests will be conducted by the University of the Free State, Exercise and Sport Science Department.

The aim of the research project is to determine the level of core stability and then compare it with the athletic performance and determine if these two variables have a correlation. This will be done by collecting measurements regarding the level of core stability using three tests to assess core endurance and core strength respectively and one test to measure core motor control; lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of a medicine ball chest throw; lower body speed and power, measured by the time in seconds during the 40m sprint and agility and power, measured by the time in seconds to complete a T-test.

All female sports teams of the University of the Free State will be visited where information regarding the testing will be explained. It will also provide an opportunity for athletes to volunteer as participants in the study. The information gathered from the tests will be analysed and the results will be used to develop sport enhancement programs for future athletes.

This study is beneficial for current participants, athletes, coaches and sport professionals. This study will also assist coaches, athletes and rehabilitation professionals with exercise program prescription that enhances athletic performance.

Participants will not be placed at risk and the information gathered will be handled with confidentiality by the researcher. All participants will complete an informed consent form. Participation is voluntary. Athletes may decide to not partake in the study.

Please contact me with any questions: 051 401 7965 or debruinm@ufs.ac.za.

Regards

Researcher
Miss M. de Bruin

APPENDIX H - ETHICAL APPROVAL LETTER

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

18-Jun-2019

Dear **Miss Marizanne De Bruin**

Ethics Clearance: **The relationship between core stability and athletic performance among female university athletes**
Principal Investigator: **Miss Marizanne De Bruin**
Department: **Exercise and Sport Sciences Department (Bloemfontein Campus)**

APPLICATION APPROVED

Please ensure that you read the whole document

With reference to your application for ethical clearance with the Faculty of Health Sciences, I am pleased to inform you on behalf of the Health Sciences Research Ethics Committee that you have been granted ethical clearance for your project.

Your ethical clearance number, to be used in all correspondence is:**UFS-HSD2019/0447/2506**

The ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the HSREC for approval to ensure we are kept up to date with your progress and any ethical implications that may arise. This includes any serious adverse events and/or termination of the study.

A progress report should be submitted within one year of approval, and annually for long term studies. A final report should be submitted at the completion of the study.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa www.ufs.ac.za

APPENDIX I - LANGUAGE EDITING REPORT

Confirmation of Language Editing

10 July 2020

To whom it may concern,

CONFIRMATION OF LANGUAGE EDITING

In relation to the MA Dissertation of Marizanne de Bruin, entitled:

THE RELATIONSHIP BETWEEN CORE STABILITY AND ATHLETIC PERFORMANCE AMONG FEMALE UNIVERSITY ATHLETES

To be submitted in fulfilment of the degree M.A. in Human Movement Science at the University of the Free State, I, in my capacity as Language Practitioner, confirm that the abovementioned document has been edited with specific focus on the following:

- Language use and spelling (UK English)
- Coherence and linguistic flow
- Consistency in terminology and formatting

In relation to the above, Track Changes were used in MS Word to indicate changes, and comments were provided where necessary. Please note that changes are made solely at the client's discretion and remain their own responsibility. Any comments provided are purely suggestions and reflect the best efforts and opinions of the Editor and not necessarily subject-specific expertise. It remains the responsibility of the client to confirm the content of their final submission.

For any questions, please feel free to contact me at guillaume.annam@gmail.com during normal business hours.

Kind regards,

A.M. Guillaume-Combrink
LANGUAGE PRACTITIONER