The relationship between change of direction ability, acceleration and postural control of female university netball players

by

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DECLARATION

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SUMMARY

The ability to change direction while at a high entry velocity is a highly valued athletic quality among many invasion team sports. In combination with an athlete's cognitive perceptual ability, change of direction speed (CODS) is a vital component of effective and efficient agility manoeuvres. Due to its proposed link with agility performance, CODS is extensively researched. The relationship between CODS performance and other physical factors, such as acceleration and lower limb muscle qualities, have frequently been investigated. However, literature regarding the relationship between CODS ability and postural control (PC) is scarce. Maintaining control of the body's centre of mass during a rapid directional change could potentially benefit the transition from deceleration to a subsequent acceleration.

Recently the validity of many of the performance tests used to assess change of direction speed have been criticised. Many of the tests are suggested to favour athletes with superior acceleration abilities, thus masking the actual ability to change direction. The change of direction deficit is proposed as a practical method to truly measure an athlete's ability to decelerate and subsequently accelerate in a new direction. The COD deficit was calculated as the difference between the best 505-CODS test time and a 10m straight-line sprint (SLS) time (COD deficit = CODS test time – 10m sprint). A low COD deficit indicates a short time was taken to change direction while at a high entry velocity. Using the 505-CODS test, the turning ability of each leg can be assessed.

The primary aim of the study was to determine the relationship between CODS, acceleration and PC. The secondary aim was to evaluate the relationship between sprinting spatiotemporal gait variables with acceleration and change of direction speed.

A total of 38 female university netball players (age = 19.5 ± 1.22) from the same club volunteered to participate in the study. The participants performed a series of tests to assess the bio-motor abilities. Each athlete performed three trials of a 20m SLS (with 5m, 10m and 20m split) and the three trials of the 505-CODS test, turning with both limbs. The best performances of the three trials were used. Single leg postural control (PC) was measured with the ISway accelerometery system using the modified Clinical Test for Sensory Interaction on Balance (mCTSIB) protocol. Gait variables were determined with timing gates and an Optogait system.

Spearman's correlation was used to explore the relationships between the variables. Moderate positive significant correlations were found between the total time of the 505-CODS test and the COD deficit (r=0.41-0.49; p<0.01). The 505-CODS test time was found to have a moderate to strong positive significant correlation to SLS times (r=0.37-0.56; p<0.01). In contrast, the COD deficit was found to have a moderate to strong inverse relationship with acceleration performances (r = -0.32 to -0.54; p<0.05). Both the 505-CODS test and the COD deficit were found to have no significant correlation with PC (p>0.05).

Regarding the spatiotemporal gait variables, there was a moderate to large positive significant correlation between ground contact time (GCT) and SLS at all split times (r=0.38-0.60; p<0.05). Stride frequency (SF) had a moderate inverse significant correlation with the 20m split SLS time (r=-0.42; p=0.01). When compared to the 505-CODS test, there was a moderate inverse correlation with the SF and 505-CODS test time (r=-0.36 to -0.41; p<0.5). 505-CODS test turns with the dominant leg were shown to have a moderate positive significant correlation with GCT.

In conclusion, using the COD deficit may be a practical tool for coaches to use to determine an athlete's ability to change direction while at a high entry velocity. Faster university netball players demonstrated a longer COD deficit; thus, coaches are encouraged to enhance their athletes' ability to rapidly decelerate in a controlled manner so that the time taken to turn is minimised.

Key words: Change of direction speed, change of direction deficit, postural control, netball

OPSOMMING

Die vermoë om van rigting te verander met 'n hoë aanvangsnelheid is ‘n atletiese eienskap wat onder baie spansportsoorte, veral sportsoorte met indringingskenmerke, van hoë waarde geag word. In kombinasie met 'n atleet se kognitiewe waarnemingsvermoë, is rigtingveranderingspoed (RVS) 'n belangrike deel van effektiewe en doeltreffende ratsheidsmaneuvers. RVS is al deeglik ondersoek as gevolg van die veronderstelde skakel met ratsheidvermoë. Die verband tussen RVS-prestasie (performance) en ander fisieke faktore, soos versnelling en spierkrag van die onderste ledemate, word gereeld ondersoek. Literatuur oor die verband tussen RVS-vermoë en posturale beheer (PB) is egter skaars. Om in beheer te bly van die liggaam se middelpunt tydens 'n vinnige rigtingverandering kan moontlik die oorgang van spoedvermindering tot 'n daaropvolgende spoedversnelling vergemaklik.

Onlangs is die geldigheid van baie van die prestasietoetse wat gebruik word om die verandering-van-rigting spoed te assesseer, gekritiseer. Daar word aangevoer dat heelwat van die toetse atlete met beter versnellingsvermoëns bevoordeel. Sodoende word die werklike vermoë om rigting te verander, verbloem. Die verandering-van-rigting-tekort (VVRT) word voorgestel as 'n praktiese metode om 'n atleet se ware vermoë om te versnel en daarna in 'n nuwe rigting te versnel, te meet. Die VVRT word bereken as die verskil tussen die beste 505-RVS toetstyd en 'n 10m reguitlyn naellooptyd (VVRT = RVS toetstyd - 10m sprint). 'n Lae VVRT dui aan dat dit 'n kort tydjie geneem het om rigting te verander tydens 'n hoë beginsnelheid. Met behulp van die 505-RVS toets kan die draaivermoë van elke been bepaal word.

Die primêre doel van die studie was om die verband tussen RVS, versnelling en PB te bepaal. Die sekondêre doelwit was om die verwantskap tussen tyd-ruimtelike hardloopveranderlikes te evalueer met versnelling en RVS. Altesaam 38 vroulike universiteit-netbalspelers (ouderdom = 19.5 ± 1.22) van dieselfde klub het vrywillig aan die studie deelgeneem. Die deelnemers het 'n reeks toetse uitgevoer om hul bio-motoriese vermoëns te assesseer. Elke atleet het drie herhalings van 'n 20m SLS (met 5m, 10m en 20m breuke) uitgevoer en drie toetse van die 505-CODS toets, draai op albei bene. Die beste telling van die drie herhalings is gebruik. Enkelbeen posturale beheer (PB) is gemeet met die ISway versnellingsmeterstelsel met behulp van die gewysigde kliniese toetse vir sensoriese interaksie vir balans (mCTSIB) protokol.

Spearman se korrelasie is gebruik om die verhoudings tussen die veranderlikes te ondersoek. ‘n Matige, positief beduidende korrelasie is gevind tussen die totale tyd van die 505-RVS toets en die RV tekort (r = 0,41-0,49; p <0,01). Die 505-CODS toetstyd het bevind dat 'n matige tot sterk positiewe beduidende korrelasie bestaan met SLS-tye (r = 0,37-0,56; p <0,01). In teenstelling hiermee is bevind dat die VVRT 'n matige tot sterk omgekeerde verhouding met versnellingsprestasies (r = -0.32 tot -0.54; p <0.05) gehad het. Beide die 505-RVS-toets en die VVRT het geen beduidende korrelasie met PB (p> 0.05) gehad nie.

Met betrekking tot die tyd-ruimtelike hardloopveranderlikes was daar 'n matige tot groot positief beduidende korrelasie tussen grondkontaktyd (ground contact time, GCT) en SLS op alle fraksietye (r = 0,38-0,60; p <0,05). Frekwensie van treë (Stride frequency, SF) het 'n matige omgekeerde beduidende korrelasie met die 20m fraksie SLS tyd (r = -0.42; p = 0.01). In vergelyking met die 505-CODS toets was daar 'n matige omgekeerde korrelasie met die SF en 505-CODS toetstyd (r = -0.36 tot -0.41; p <0.5). 505-CODS toetsdraaie op die dominante been het getoon dat dit 'n matige positiewe beduidende korrelasie met GCT het.

Ter afsluiting, die gebruik van die VVRT kan 'n praktiese hulpmiddel wees. Afrigters kan dit gebruik om 'n atleet se vermoë te bepaal om rigting te verander teen 'n hoë aanvangsnelheid. Vinniger universiteitsvlak netbalspelers het 'n langer VVRT getoon. Daarom word afrigters aangemoedig om hul atlete se vermoë te verbeter om vinnig in gekontroleerde omstandighede te versnel om sodoende omdraaityd te verminder.

Sleutelwoorde: Verandering-van-rigting spoed, verandering-van-rigting tekort, postuurbeheer, netbal

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Nil arduum volentibus

Nothing is impossible for the valiant

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LIST OF KEY TERMS

Acceleration	A maximal velocity sprint of not more than 30m
Agility	The ability to change direction, velocity, or mode in response to a stimulus.
COD	The specific event of changing direction.
COD deficit	A metric proposed which gives an isolated measure of the ability to change direction speed while at a high entrance velocity. It is calculated by subtracting the time of a straight-line sprint from the total time of a CODS test of equal distance.
CODS	The ability to decelerate, reverse or change movement direction and accelerate again.
Postural control	A complex skill based on the interaction of dynamic sensorimotor processes. The two functional goals of postural control are postural equilibrium and postural orientation.

LIST OF ABBREVIATIONS

COD	Change of direction
COD deficit	Change of direction deficit
CODS	Change of direction speed
COP	Centre of pressure
CDP	Computerised dynamic posturography
FT	Flight time
GCT	Ground contact time
LOS	Limit of stability
mCTSIB	modified Clinical Test for Sensory Interaction on Balance
OSI	Overall stability index
PC	Postural control
SF	Stride frequency
SL	Stride length
SLS	Straight-line sprint
SOT	Sensory organisation test

CHAPTER ONE

INTRODUCTION

1.1. OVERVIEW OF LITERATURE

Evaluation of an individual's athletic performance in a quantitative manner is a crucial tool for coaches, practitioners and researchers. There are specific functional skills which can be identified as important physical components required to obtain athletic excellence. These skills can be expressed as bio-motor abilities (Singh, 2010). Each specific sport, or sport type, has its own set of goals and objectives which must be reached to be successful in a competitive setting. Achieving these specific goals and objectives is made easier if efficient performance of specified bio-motor abilities is achieved. Bio-motor abilities deemed important for invasive type team sports (e.g. netball, soccer, basketball, rugby etc.) include strength, power, agility, balance and acceleration (Bourgeois, 2017; Hammami, Behm, Chtara, Othman & Chaouachi, 2014; Loturco, Nimphius, Kobal, Bottino, Zanetti, Pereira & Jeffreys, 2018; Sekulic, Spasic, Mirkov, Cavar & Sattler, 2013; Thomas, Comfort, Jones & Dos'Santos, 2017; Thomas, Ismail, Simpson, Comfort, Jones & Dos'Santos, 2017; Vescovi & Mcguigan, 2008; Young, Miller & Talpey, 2015).

Quantitative assessment of these abilities can be useful in many scenarios. It can be used to identify the strengths and weaknesses of an individual or a team, which could assist strength and conditioning coaches to create individualised training programmes in order to improve overall athletic performance. The assessment of the effectiveness of specific training and rehabilitation programmes has also become an aim for testing athletes. It is important to note that most bio-motor abilities are not individual components. Instead, a combination of bio-motor abilities often makes up a new bio-motor ability (Singh, 2010). This understanding of these abilities has led to many researchers conducting studies which investigate the inter-relations of selected bio-motor performances. Identifying significant relationships could assist coaches in developing training methods which could improve more than one individual skill at a time or improve a skill which could affect the performance of another skill. To accurately measure the performance of a specific bio-motor ability, the test used should isolate the chosen bio-motor ability as much as possible, without other physical components affecting the results of the test.

The unpredictable nature of invasive team sports has led to agility being viewed as an important skill for athletes which participate in these types of sports. In conjunction with an athlete's cognitive perceptual ability, change of direction speed (CODS) is a vital component of effective and efficient agility manoeuvres (Gabbett, Kelly & Sheppard, 2008; Nimphius, Callaghan, Bezodis & Lockie, 2017; Sheppard & Young, 2006; Young, James & Montgomery, 2002). In recent literature it is widely acknowledged that to assess agility ability, a reactive element should be incorporated in the test (Gabbett *et al.*, 2008; Young, Dawson & Henry, 2015). A test with pre-planned directional changes measures an athlete's CODS ability (Jones, Bampouras & Marrin, 2009).

Due to its proposed link with agility, the ability to change direction while at speed is a frequently evaluated skill by strength and conditioning professionals. Despite this, there does not seem to be one universally used field test to assess this ability. Coaches and researchers have created and adapted numerous tests to incorporate appropriate sport specific movements applicable to their sport of interest. These various "sport-specific" tests attempting to measure COD ability have immensely different characteristics from one another. Examples of these characteristics include the total distance covered, the amount of directional changes, the angle of directional change and the total time taken to complete the tests.

Some authors suggest that many of the commonly used tests fail to truly assess one's ability to decelerate and subsequently accelerate toward a new direction (Nimphius, Geib, Spiteri & Carlisle, 2013; Sayers, 2015). It is argued that many of these existing tests place distinct demands on other combinations of physical capacities. The structure of some CODS tests has been suggested to favour those with superior acceleration or speed. Some tests are so long in time and distance, that anaerobic capacity has been proposed to be a critical factor to performance (Nimphius *et al.*, 2017) These manifestations of other physical capacities in many traditional

CODS tests could make it difficult for coaches and researchers to know whether changes in performance are due to improved COD ability or improvements of other physical capacities.

To eliminate these limitations in traditional CODS tests, it has been suggested that alternative methods should be explored to assess CODS (Nimphius, Callaghan, Lockie & Spiteri, 2016; Nimphius *et al.*, 2013; Sayers, 2015). Sayers (2015) proposed that the total testing distance should be as short as possible to prevent other factors from skewing the performance of the CODS test. The researchers suggest that CODS ability should be assessed over 1m or less from the turning point. However, sophisticated equipment (for example 3D motion capture systems) is required to accurately monitor the movements during a test over such a short distance. Furthermore, the reliability of the CODS test decreases as the testing distance becomes shorter (Sayers, 2015). These limitations prevent this proposed method of assessing CODS from being a practical field-based test to measure an athlete's CODS ability.

Another solution attempting to isolate COD ability is the proposed metric termed the COD deficit designed by Nimphius, Geib, Spiteri and Carlisle (2013). The COD deficit is calculated as the difference between the total time of a COD test and the total time of a straight-line sprint (SLS) test. The distance of the SLS test should be the same as the total recorded distance covered in the CODS test. The COD deficit removes the confounding factor of linear sprinting ability, thus allowing practitioners to have a more isolated measure of the ability to change direction while at a high entry velocity. This metric could be calculated for any CODS test as long as the linear sprint time of equal distance is available. For example, in previous research COD ability was evaluated with the COD deficit using the 505-CODS test (Cuthbert, Thomas, Dos'Santos & Jones, 2017; Dos'Santos, Thomas, Jones & Comfort, 2018; Nimphius *et al.*, 2016), the pro-agility test (Nimphius *et al.*, 2013) and the zigzag test (Loturco *et al.*, 2018). The COD deficit that has also been suggested to be a useful tool is assessing the asymmetries in the turning ability between legs (Dos'Santos *et al.*, 2018).

Previous studies investigating the factors thought to affect an athlete's ability to change direction while at a high entry velocity, focused on CODS performances relationship with SLS performance and lower limb muscle qualities (e.g. strength, power and reactive power). Postural control has been suggested to have a potential influence on CODS ability, however, literature regarding this relationship is scarce (Lockie, Callaghan, Jeffriess & Luczo, 2016; Sekulic *et al.*, 2013). When transitioning from a deceleration phase to a subsequent acceleration phase during a directional change, CODS could be influenced by the ability to maintain control of the body's centre of mass. Efficient control of posture could be required for the optimal technique used when changing direction.

Postural control has been shown to play a role in many athletic activities, however, its role in athletic performance among different sport types is unclear (Hammami *et al.*, 2014; Hrysomallis, 2011). Postural control is believed to have two functional goals: postural equilibrium and postural orientation. Sensory information obtained from the somatosensory, visual and vestibular systems are important to correctly alter posture so that postural equilibrium and postural orientation are maintained (Hrysomallis, 2007). Static balance tests such as the modified clinical test of sensory interaction on balance (mCTSIB) have been used to determine an athlete's ability to integrate between sensory systems by being exposed to different conditions (Hammami *et al.*, 2014). The dependence from each specific sensory input to organise posture is influenced by the requirements or objectives of each sporting discipline. For example, invasive team sport athletes must control their posture to execute a variety of skills (e.g. acceleration, changes of direction, catching, passing, shooting etc). While performing these skills, visual information about the positioning of team members, the opponent and the ball must be processed. Therefore, being less reliant on visual inputs to maintain postural control could enable a team sport athlete to efficiently execute the required skill.

Netball is a popular team sport internationally which is predominantly played by women (Thomas, Ismail, *et al.*, 2017). Hetherington *et al.* reported in 2009 that the sport was played in over 70 countries by more than 20 million people. Thomas *et al.* (2017) recommend that performance anaerobic tasks are vitally important for netball. Players must be able to tolerate the movements in the high paced game which frequently involves sudden accelerations, sprints, jumps and directional changes. In netball, the frequency of these types of movements have been reported to vary among the player positions (Davidson & Trewartha, 2008; Fox, Spittle, Otago & Saunders, 2013). Consequently, certain movement tasks are deemed more important to specific player positions. This would likely mean that players in distinct positional areas excel at performance tests which assess movement patterns important to the specific position's role. This statement is supported by a study which found that players in the central positions had superior performances in a range of tests when compared to players in attacking and defending positions (Thomas, Ismail, *et al.*, 2017). This type of position-specific information could assist coaches and practitioners in making appropriate individualised training programmes in line with the position-specific demands experienced in a match. Furthermore, this study showed that the typical physical profile (i.e. height and body weight) can also differ across positional areas.

As mentioned, CODS is regarded as a distinct bio-motor ability, differing from agility. Furthermore, COD deficit may be regarded as a more accurate and pure representation of COD ability. These concepts are relative new developments in the field of testing team sport athletes; therefore, at the moment there is limited research on this topic. Results from this study should contribute to the current gap in our knowledge of CODS in team sport, specifically involving women. In netball, with its unique positional requirements, CODS is a critical skill to have. Reporting on the interrelations between various bio-motor abilities could provide information to assist in determining the optimal methods for testing and training these movement abilities. The current study could provide useful information to coaches and trainers for the development of CODS in netball.

1.2. AIMS OF THE STUDY

The primary aim of this study was to determine the relationship between change of direction speed, acceleration and postural control among university level female netball players. The secondary aim was to evaluate the relationship between sprinting spatiotemporal gait variables with acceleration and change of direction speed.

1.3. OBJECTIVES

The objectives of the current study were:

1. To determine the inter-relationships between change of direction speed (505-CODS time), COD deficit and acceleration ability.
    a. The 505-CODS test and the COD deficit
    b. The 505-CODS test and acceleration
    c. The COD deficit and acceleration
2. To determine the inter-relationship between change of direction speed and postural control ability.
3. To investigate the differences in leg imbalance percentages for change of direction speed ability quantified using the 505-CODS test compared to using the COD deficit.
4. To explore whether players of specific positional areas display any significant differences among each other with regards to physical characteristics.
5. To investigate which of the four single leg stance conditions of the mCTSIB protocol displayed the most amount of postural sway.
6. To determine if selected spatiotemporal gait variables (stride length, stride frequency, ground contact time and flight time) measured during the straight-line sprint are significantly correlated to
    a. Acceleration (5m, 10m and 20m split times)
    b. Change of direction speed (505-CODS and the COD deficit)

1.4. HYPOTHESES

The researchers hypothesised that:

1. The two methods of assessing change of direction speed (505-CODS test and the COD deficit) would reveal a significant positive inter-relationship with one another, while change of direction speed evaluated as the total time of the 505-CODS test would reveal a significant positive inter-relationship with acceleration, whereas change of direction

speed evaluated via the COD deficit would not reveal a significant positive inter-relationship with acceleration.

2. There will be no significant inter-relationship between change of direction speed and postural control.
3. The asymmetries between legs for change of direction speed ability would be significantly larger when using the COD deficit compared to using the total time of the 505-CODS test.
4. There would be a significant difference in the physical characteristics of netball players from different positional areas.
5. The netball players would display the most amount of postural sway during condition 4 (eyes closed and on the foam surface) of the mCTSIB protocol.
6. The spatiotemporal variables measured during the straight-line sprints would be significantly correlated to acceleration and change of direction speed measured as the 505-CODS test time, whereas no significant correlation would be found between the spatiotemporal variables and the COD deficit.

1.5. VARIABLES

2.1.1. DEPENDENT VARIABLES

Performance test variables: 505-CODS test time(s); COD deficit (s); between leg CODS asymmetry (%); 5m, 10m and 20m sprint times (s); postural control (jerk)

Spatiotemporal variables: stride length (m); step frequency (steps/s); ground contact time (s); flight time (s)

2.1.2. INDEPENDENT VARIABLES

Standing height (cm); body mass (kg); playing position

1.6. DELIMITATIONS

Only female netball players aged 18 to 22 at the time of the testing were used. At the time of testing, all players were busy with the same pre-season programme. Testing was only conducted once, and the best performance was taken in the tests that consisted of more trials.

1.7. ASSUMPTIONS

It was assumed that the players were taking part out of their own free will and that there was no dishonesty concerning information for the inclusion and exclusion criteria. Participants were informed not to do any strenuous exercise 24 hours prior to the testing and not to eat 60 minutes prior to testing. It was presumed that these instructions were followed. Furthermore, it was assumed that all the players performed all of the tests to the best of their abilities. The equipment used to measure the performances were correctly calibrated and assessed prior to testing. To assure the testing procedures were done and recorded appropriately, MSc and PhD students who were familiar with the equipment and tests oversaw the testing procedure. It was assumed that these research assistants were dedicated to the data collection process and gave their best effort at the time of testing.

1.8. OUTLINE OF THE THESIS

Chapter Two contains the theoretical background for the current study by reviewing relevant literature on the relationship between the selected motor tasks among athletes. Furthermore, an overview of netball will be given to better understand the game's physical demands. In Chapter Three, the detailed methods of data collection are explained, while Chapter Four contains the results of the current study. Finally, in Chapter Five a discussion of the main findings is done. This chapter will also include the overall conclusion to the study, limitations of the study and recommendations for future research. The referencing style used in the current study is the "Harvard – Stellenbosch University" style from Mendeley Desktop's reference library.

CHAPTER TWO

THEORETICAL BACKGROUND

2.1. INTRODUCTION

In this chapter, a contextual foundation of the bio-motor abilities identified as indicators of athletic performance will be discussed. First off will be the specific bio-motor abilities typically identified as important for a variety of team sports. This is done to create a framework as to why the bio-motor abilities investigated in this current study were selected.

Secondly, a detailed background of change of direction speed (CODS) will be discussed. This will help to explain its importance in many invasive team sports and how it is related to agility, which is regarded as an important skill for team athletes. An in-depth discussion will be conducted into the factors that have been suggested to have a potential effect on this direction changing ability. Furthermore, different tests designed to evaluate CODS will be touched on, as well as the limitations that these tests have on assessing an individual's direction changing ability when at speed. This will be followed by an explanation of acceleration ability in team sports and the spatiotemporal variables affecting its performance.

In the penultimate section a detailed explanation of the intricacy of postural control will be the topic. To create a better understanding of this bio-motor ability, the resources on which the maintenance of adequate postural control relies on will be the focal point. Tests and technology which are used to assess postural control in other studies will be mentioned. Lastly, the role that postural control plays in sport performance will be discussed. In the final section, an explanation of the sport of netball will be given, along with a description of the typical movement patterns which occur in the sport. Furthermore, a physical profile of netball players across positions will be explained.

2.2. BIO-MOTOR ABILITIES IN TEAM SPORTS

"Biomotor abilities" is the terminology used to describe the underlying functional skills required for efficient athletic performance (Singh, 2010). These abilities can be described as the building blocks of athletic performance. Basic examples of these functional skills include strength, power, endurance, speed, coordination, flexibility, agility and postural control. While improvement of these abilities is possible through training, genetics play a role in the baseline performance and rate of improvement of the ability.

Various tests have been developed and categorised to test a specific bio-motor ability. For example, a test emphasising quickness and high frequency movements can be used to measure speed performance. Another example would be to lift a maximal load to determine strength performance. However, it is important to note that many movement tasks involve a combination of two or more bio-motor abilities which often result in a new bio-motor ability (Singh, 2010). For instance, tasks where strength and speed abilities are almost equally important, such as jumping tasks, result in another bio-motor ability i.e. power. Agility performance is another example of a bio-motor ability which is dependent on a complex combination of other bio-motor abilities. Multiple bio-motor abilities have been suggested to have an underlying influence in agility performance. This complex bio-motor ability will be discussed in more detail in the next section.

The importance of a certain bio-motor ability in sport depends on the goals and objectives associated with the particular type of sport. Coaches, practitioners and researchers use tests to record the performance of the bio-motor abilities believed to be important for their specific sport of interest. The variety of tests used makes it possible to record and analyse each specific bio-motor ability and their underlying subcomponents in a quantitative manner. The quantitative data could assist coaches in identifying individuals with athletic potential (or lack thereof) required to excel in a specified position or sport (Singh, 2010). It can also be used to evaluate the effectiveness of training programmes with regards to improving selected bio-motor abilities.

Invasion team sports involve two opposing teams competing on the same field or court, where the main objectives of the game are scoring a goal or a point in the opposition team's territory and to prevent the opposition from scoring in your team's territory (Lamas, Barrera, Otranto & Ugrinowitsch, 2014; Young, Dawson, *et al.*, 2015). Examples include sports such as soccer, rugby union, rugby league, netball, hockey, basketball etc. In these types of sports, gaining and maintaining ball possession is vital for attack, while defending and regaining the ball is important to stop the opposition from scoring. Examples of bio-motor abilities which are commonly assessed in invasion type team sports include acceleration, endurance, agility and postural control (or balance).

In the current study, the inter-relations between selected bio-motor abilities will be investigated to assist in the improvement of overall athletic performance. Literature regarding many of these relationships are often inconsistent due to the variety of sport specific performance tests designed to assess a desired bio-motor ability. Significant correlations between two separate bio-motor abilities could mean that the improvement of one bio-motor ability would in turn assist the improvement of a separate bio-motor ability. Furthermore, this study will be investigating the use of a relatively novel performance test (the COD-deficit). The addition of norm values of bio-motor performance tests from athletes of specific sporting codes could assist future practitioners and researchers interested in using the test.

2.3. CHANGE OF DIRECTION SPEED

In this section, change of direction speed (CODS) will be explained to understand its relevance in an invasive team sport. The difference between agility and CODS will be briefly explained to create a platform to understand their relation to one another. This will be followed by a description of the tests used to measure CODS by coaches and researchers in the past. Finally, the possible factors suggested to affect CODS ability will be discussed.

Being able to rapidly change direction while running at a high velocity, is deemed an essential skill for various field and court-based sports (Barber, Thomas, Jones, McMahon & Comfort, 2015; Brughelli, Cronin, Levin & Chaouachi, 2008; Fox *et al.*, 2013; Fox, Spittle, Otago & Saunders, 2014; Gabbett *et al.*, 2008; Jones *et al.*, 2009). Previously, this skill would often be described as agility, however, recent studies seem to agree that agility is more accurately defined as "a rapid whole-body movement with change of velocity or direction in a response to a stimulus" (Sheppard & Young, 2006, p919). This more comprehensive definition considers that the decision to suddenly change direction or velocity is a response to an opponent's actions to either evade a defender during an attacking situation or to place an attacker under pressure to regain possession when defending. Therefore, perceptual and decision-making skills are an integral part of agility, along with the physical demands required to rapidly change direction. Figure 2.1 is a diagram proposed by Young *et al* (2002) that illustrates the factors which are suggested to influence agility performance.

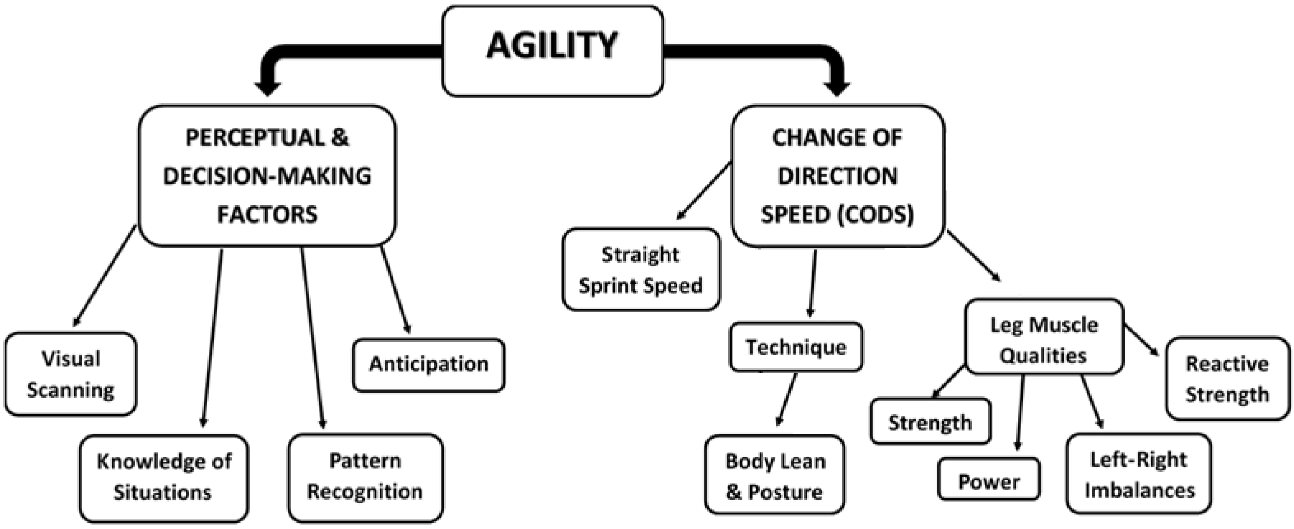

Figure 2.1: Proposed model of agility and its subcomponents (modified from Young et al. 2002)

Researchers suggest that to truly assess agility ability, performance tests for agility must include a reactive stimulus which dictates the athlete's directional change to better simulate in-game situations (Gabbett *et al.*, 2008; Sheppard & Young, 2006; Sheppard, Young, Doyle, Sheppard & Newton, 2006; Young, Miller, *et al.*, 2015). Performance tests where the directional changes are pre-planned are suggested to assess change of direction speed (CODS) (Young *et al.*, 2015).

Jones *et al.* (2009; p97) defined CODS as "the ability to decelerate, reverse or change movement direction and accelerate again". Along with perceptual and decision-making skills, CODS has often been regarded an important sub-factor of agility (Barber *et al.*, 2015; Sheppard & Young, 2006).

However, in a recent review Young *et al.* (2015) suggests that CODS should be considered as a separate skill to agility, opposed to being a sub-component of agility. This suggestion is derived from some studies finding that performances of reactive and pre-planned CODS tests are not significantly correlated to one another (Lockie, Jeffriess, Mcgann, Callaghan & Schultz, 2014; Spiteri, Nimphius, Hart, Specos, Sheppard & Newton, 2014). Other studies found moderate correlations between reactive agility and CODS tests involving identical movement patterns (Gabbett *et al.*, 2008; Scanlan, Humphries, Tucker & Dalbo, 2014).

Lockie *et al.* (2014) recorded the reactive agility and planned CODS performances of 20 male basketball players (age=22.30±3.97), which included ten semi-professional players (age=21.4±3.13) and ten recreational players (age=23.20±4.66). This study used the Y-shaped reactive agility and planned CODS test. This test involves a short 5m acceleration followed by a (left or right) directional change of about 45°, after which another 5m burst is made to the finishing gates. The best performance over three recorded trials was used for a directional change to the left and to the right, for both the reactive and the planned assessments. For the reactive agility Y-shaped test, the direction of the cut was dictated by a flashing gate which was triggered to randomly flash at either the right or left sided finishing gate. The results indicated that planned left CODS was not significantly correlated to any of the reactive agility assessments. In contrast, the planned right CODS performance was shown to be moderately correlated to the reactive right agility performance (r=0.457). It was not reported if the left and right performances were related to limb dominance.

Another study comparing the performances between reactive agility and planned COD tests was conducted by Spiteri *et al* (2014). The participants of this study were 12 female basketball players which played in their national basketball league (age=24.25±2.55). The researchers investigated whether the performances in two CODS tests (505-CODS and T-test) were significantly correlated to a reactive agility test. The results indicated that both the planned

CODS test performances were not significantly correlated to the reactive agility test performance. In contrast with the study by Lockie *et al*. (2014), the movements executed in the CODS tests differed to the movements involved in the reactive agility test which could have influenced the findings. However, the researchers found that the planned CODS tests performances, the 505-CODS and the T-test, were strongly correlated to one another ($r=0.810$; $p<0.001$). This would suggest that the CODS tests assess the same ability, whereas the reactive agility test performance is reliant on perceptual and decision-making factors.

The key role that perceptual and decision-making ability has on reactive agility performances is highlighted in a study by Scanlan *et al.* (2014). The participants were 12 male basketball players competing in a provincial level league (age=25.9±6.7). The basketball players performed a reactive agility test which was recorded with a high-speed camera. The reactive agility test was set up in a Y-shaped design with timing gates to the left and right side. A tester was positioned 5m in front of the starting-point, facing the participant. Participants assumed a standing preparatory position at the starting-line and the timing began when the tester initiated movement. Participants were required to move forward, then laterally, to the left or the right, mirroring the direction taken by the tester. Using the high-speed video footage, the researchers determined the response time and the decision-making time. Response time was recorded as the duration from initial movement of the tester until the first timing gates were triggered by the participant. Decision-making time was calculated as the time interval from the first identifiable foot contact which shows the directional change of the tester until the first identifiable foot contact initiating the response of the participant. The total movement time of the reactive test was also recorded. Using the same course outline which was used in the reactive agility test, the participants were recorded doing pre-planned directional changes toward either the left or right sided timing gates. Analysis of the results indicated that the cognitive measures had a greater influence on reactive agility performances than the planned CODS. Decision-making time and response time showed large to very large correlations to the reactive test ($r=0.58$ and $r=0.76$). Although CODS and the reactive agility test also had moderate correlation ($r=0.43$), the correlation coefficient was smaller compared to the correlation of the cognitive measures.

Furthermore, several studies have determined that high-level athletes are significantly superior to lower-level athletes when performing reactive agility tests. In contrast, performances in CODS tests did not separate higher- and lower-standard groups (Gabbett *et al.*, 2008; Lockie *et al.*, 2014; Sheppard *et al.*, 2006). Sheppard *et al* (2006) assessed the reactive agility and planned CODS performances of 38 male Australian football players (age=21.8±3.2), competing in the senior Western Australian Football league. The high-performance group consisted of 23 players (age=23.1±3.7), while the other 14 made up the lower-performance group (age=19.9±1.5). The reactive agility test and the planned CODS test used in this study was the same as the one used by Scanalan *et al.* (2014), which has been described previously. Results indicated that the high-performance group was significantly better at the reactive agility task. However, there was no significant difference among player levels regarding the planned CODS test. A similar finding was reported in the previously mentioned study by Lockie *et al.* (2014). The semi-professional basketball players performed significantly better than their recreational counterparts regarding the reactive agility test. The planned CODS test performance did not significantly differentiate between the skill levels.

Regardless of whether CODS is a linked or separate component of agility, it is still regarded as an important skill to develop in invasive type team sport (Barber *et al.*, 2015; Lockie, Schultz, Callaghan & Jeffriess, 2013; Nimphius *et al.*, 2013). Attacking from set-piece situations frequently involves predetermined runs and sudden directional changes to distract defenders or to create space for scoring opportunities. Additionally, the mechanics involved in pre-planned CODS tasks are identical to reactive agility tasks, since both involve a controlled deceleration and directional change followed by sudden acceleration. The joint loadings experienced during pre-planned directional changes could form a physical foundation for the higher joint loadings experienced in reactive agility situations during a match (Nimphius *et al.*, 2016).

Misidentification or improper assessment of a bio-motor ability such as agility and its subcomponent CODS can become problematic to practitioners. Simple misunderstandings could cause training programs to be developed which fail to improve the desired abilities or which potentially focuses on an ability that has a restricted period for adaptation (Nimphius *et al.*, 2017).

2.3.1. POSSIBLE FACTORS INFLUENCING CHANGE OF DIRECTION SPEED

Several factors have been suggested to affect the performance of a CODS task. A model developed by Young, James and Montgomery (2002) suggests that CODS performance is dependent on technique, straight-line sprint (SLS) ability and leg muscle qualities. This model has been used as a framework for a number of studies investigating the factors influencing performance of CODS tasks (Brughelli *et al.*, 2008; Dos'Santos, Thomas, Jones & Comfort, 2017; Sheppard & Young, 2006). Researchers have frequently examined the role that straight-line speed and/or lower limb explosive strength have on pre-planned CODS tests (Cuthbert *et al.*, 2017; Dos'Santos *et al.*, 2018; Gabbett *et al.*, 2008; Jones *et al.*, 2009; Köklü, Alemdaroglu, Koz & Ersoz, 2014; Little & Williams, 2005; Lockie *et al.*, 2014; Lockie, Schultz, *et al.*, 2013; Markovic, 2007; Nimphius *et al.*, 2013; Nimphius, Mcguigan & Newton, 2010; Nimphius *et al.*, 2016; Salaj & Markovic, 2011; Sassi, Dardouri, Yahmed, Gmada, Mahfoudhi & Gharbi, 2009; Sayers, 2015; Sekulic *et al.*, 2013; Sheppard *et al.*, 2006; Vescovi & Mcguigan, 2008; Young *et al.*, 2002; Young, Miller, *et al.*, 2015).

Some authors suggest that maintaining control of body posture is an additional key feature to CODS performance (Lockie *et al.*, 2016; Lockie, Schultz, *et al.*, 2013; Miller, Herniman, Ricard, Cheatham & Michael, 2006; Sekulic *et al.*, 2013), although literature regarding this relationship is scarce. Other factors such as technique and anthropometric characteristics have also been proposed to effect CODS performance (Sheppard & Young, 2006). The angle at which the change of direction occurs have also been suggested to influence kinetic and kinematic requirements for a quick directional change (Bourgeois, 2017; Buchheit, Haydar & Ahmaidi, 2012).

Closer inspection of the results of the studies investigating these relationships shows that literature regarding skills which influence CODS performance seems inconsistent. This is most likely due to the variations in CODS tests that were performed across investigations. The duration and amount of directional changes involved differ among tests developed to assess CODS in sport-specific situations. Such a wide variety of tests makes it exceptionally difficult to compare results of different studies. Additionally, it has been shown in a number of studies that the strength of certain relationships are gender-specific (Peterson, Alvar & Rhea, 2006; Sassi *et al.*, 2009; Sekulic *et al.*, 2013). This is another possible cause for inconsistency among findings.

In this section, research regarding the factors mentioned above will be discussed in more detail. The two main factors relating to this study are: (1) straight sprint speed and (2) postural control. Although not the focus of this study, other key factors frequently mentioned in literature (3) leg muscle qualities and (4) technique will also be explained.

In Table 2.1. a summary of the findings from some of the studies investigating the relationship between CODS performance and other physical factors is given. For relevance to the current study, the summarised table only includes the findings of the relationship between CODS tests and acceleration and/or postural control.

2.3.1.1. STRAIGHT-LINE SPRINT SPEED AND ACCELERATION

Extensive research has been done investigating the role that straight-line sprinting performance has on CODS. As mentioned earlier, Jones *et al.* (2009, p97) defined CODS as "the ability to decelerate, reverse or change movement direction and accelerate again". Inspection of this definition reveals a probable reason to why the relationship of CODS and short SLS performance is a popular topic for investigation among researchers. According to the definition, along with deceleration and the actual COD movement, acceleration is one of three factors involved in CODS performance.

The acceleration phase of a 100m sprint has previously been identified as the first 30m (Debaere, Jonkers & Delecluse, 2013), because maximal speed is usually attained shortly after this point. Due to acceleration ability being the factor of interest in these studies, most SLS test times are recorded at distances ranging from 5m (Gabbett *et al.*, 2008; Jones *et al.*, 2009; Salaj & Markovic, 2011; Sayers, 2015) to 30m (Köklü *et al.*, 2014; Nimphius *et al.*, 2016). The most commonly recorded distance across inspected studies is at the 10m point. Debaere *et al.* (2013) classify the first 10m of a maximal effort sprint as the initial acceleration phase. This is also deemed a suitable distance due to reports that most maximal effort sprints in court or field sports seldom exceed two seconds (Chandler, Pinder & Gabbett, 2014; Davidson & Trewartha, 2008; Fox *et al.*, 2013).

Despite numerous investigations regarding this relationship, results across studies are inconsistent. Previous studies have reported a wide range of the strength of relationships. The strength correlation coefficients between maximum effort SLS times and the performance of various CODS tests ranged from trivial (r=0-0.09) (Sekulic *et al.*, 2013) to nearly perfect (r=0.90-0.99) (Nimphius *et al.*, 2010).

Some authors suggest that the strength of the relationship between linear speed and planned CODS test is weaker when the angle of the COD is large (Bourgeois, 2017; Oliver & Meyers, 2009). Furthermore, studies which have recorded sprint times at more than one distance have contradicting results regarding the pattern of the relationships strength as the sprinting distance increases. Some authors reported an increase in the strength of the relationship as sprint distances increased (Gabbett *et al.*, 2008; Köklü *et al.*, 2014; Nimphius *et al.*, 2016; Sayers, 2015; Vescovi & Mcguigan, 2008), while others found the opposite to be true (Jones *et al.*, 2009; Salaj & Markovic, 2011; Sekulic *et al.*, 2013).

This further highlights the inconsistencies among literature concerning SLS performance and its link to CODS ability. These inconsistencies can most likely be attributed to the different CODS assessment tests used across studies which involve variations in distances, amount of directional changes and angles of directional change (Nimphius *et al.*, 2016; Sayers, 2015). Furthermore, the strength of the relationship between COD ability and SLS performance is suggested to be gender-specific (Sassi *et al.*, 2009; Sekulic *et al.*, 2013). In the studies where the strength of the relationships were separately investigated for male and female participants, acceleration ability displayed a stronger relationship among females compared to their male counterparts (Sassi *et al.*, 2009; Sekulic *et al.*, 2013). The inconsistent findings among literature have caused some authors to propose that SLS and CODS should be considered as two independent skills (Salaj & Markovic, 2011).

2.3.1.2. TECHNIQUE AND POSTURAL CONTROL

Executing an efficient COD requires more than just the physical factors discussed. The technical characteristics are believed to be as important for a quick COD. At the right time, correct adjustments in stride length, placement of the feet and body positioning could greatly enhance one's COD ability (Hewit, Cronin & Hume, 2013). Many of these technical aspects can be improved through appropriate cues given by the coaching staff. Literature on the technical aspects of CODS is scarce due to the expensive equipment required to investigate intricate technical differences.

Certain mechanical variables have been identified as determinants of faster CODS performance. Studies have reported greater braking and propulsive forces and shorter ground contact times during of the final foot contact when changing direction (Dos'Santos *et al.*, 2017; Spiteri *et al.*, 2014). The mechanical variables of the penultimate foot have also been investigated because of the role that it plays during deceleration (Dos'Santos *et al.*, 2017). In the study by Dos'Santos *et al.* (2017), 40 male athletes from mixed sporting disciplines (age=23±2.9) performed a modified 505-CODS test where the penultimate and final foot contacts when changing direction take place on a force plate. The researchers reported that faster CODS performance was significantly associated with shorter ground contact time (GCT) (r=0.701-0.757), greater horizontal propulsive forces (r=-0.572 to -0.611) and greater horizontal braking forces (r=-0.337).

Young *et al.* (2006) suggest that during a COD, while at speed, a forward lean and a relatively low centre of gravity is essential for optimal deceleration and sudden acceleration. These postural adjustments are believed to increase the stability, thus making it easier to control one's moving centre of mass when transitioning from deceleration to acceleration. Minimising the average ground contact time during the stance phase of the running gait has also been suggested before (Markovic, 2007). The technical requirements of the athlete are also dependent on the characteristics of the directional change. For example, during a directional change with a small COD angle, velocity is maintained during the curvilinear path. This can be termed as manoeuvrability (Nimphius *et al.*, 2017). In doing so, the clearly defined plant step present during a cutting type of COD is eliminated (Nimphius *et al.*, 2017).

An investigation done by Hewitt *et al.* (2013) is one of the few studies attempting to identify some of these technical characteristics which contribute to a fast COD. The researchers analysed video footage of New Zealand national under 21 netball players (n=22; age=19.3 ± 1.1) to determine what kinematic factors affected fast and slow change of direction acceleration times. A straight acceleration test was also performed to see if the kinematic variables differ to those in the acceleration after a COD. For the COD acceleration, participants were instructed to perform a 180° turn followed immediately by a straight sprint. The distance of the sprint was 2.5m, thus the kinematic data of only 3 steps were taken for both acceleration tasks.

The faster group for the COD acceleration task had significantly higher average step frequency than those in the slower COD acceleration group. When comparing the kinematic variables observed in the two tests, the results reveal that the COD acceleration task was associated with significantly shorter step lengths compared to the straight acceleration task. The first step of the COD acceleration task revealed a significant decrease in forward lean, while the first two steps also revealed a significantly lower knee lift.

Acceleration after a rapid COD requires the free leg to rotate toward the new direction before the supporting leg can begin to drive upward for the next step. Hewitt *et al.* (2013) suggest that the more erect posture associated with the COD acceleration task is especially advantageous if required to perform consecutive COD movements. A more erect posture would allow the free leg to be repositioned earlier for the next ground contact.

This information, however, does not provide information regarding the kinematic variables during a directional change while in motion. The COD acceleration task required the participant to do a 180° turn from a stationary start, and then accelerate. This method would eliminate the deceleration which occurs prior to changing direction when in motion. Future research on the technical aspects of CODS should try to incorporate the deceleration aspect so that the movement is more sport specific.

Although postural control (or balance ability) has been suggested to influence an athlete's COD ability (Lockie *et al.*, 2016; Miller *et al.*, 2006; Sekulic *et al.*, 2013; Sporiš, Jukic, Milanovic & Vucetic, 2010), the relationship between the two motor skills is scarcely investigated. The ability to effectively control the body's centre of mass when changing direction at high velocities could play a role in efficiently transitioning from deceleration to acceleration during a directional change. Efficient control of posture could be required for the optimal technique used when changing direction.

Sekulic *et al.* (2013) suggest that balance could have a significant impact on the efficacy of changing direction due to the "stop-and-go" nature of the movement pattern. They explain further that inertia causes the body to maintain its initial direction of movement, whereas good postural control could ensure a stable positioning for a change in direction. Being able to accurately coordinate the timing and action strength of skeletal muscles, is essential for both postural control and changing direction. This is a rarely studied factor possibly because of the challenges with accurately measuring postural control. Sophisticated equipment, such as force pressure plates, is not always financially viable. Furthermore, these tests are confined to a laboratory.

A study by Sekulic *et al.* (2013) is one of the few studies found which investigates a similar factor; however, they use the term "balance ability" instead of postural control. Using the Biodex Balance System, two separate tests were conducted to give an overall stability index (OSI) and a limit of stability (LOS) score. These two scores were compared to the times of five different pre-planned CODS tests; namely: T-test, zigzag test, 20-yard shuttle test (or pro-agility test), T180 and FWDBWD test. Table 2.2 gives a better description of each test.

Interestingly, the tests indicating "balance ability" were significantly related to performances in the CODS tests only among the male participants, not females. The influence of "balance ability" was most pronounced in the T-test and the zigzag test, which is suggested to be caused by the lateral and semi-lateral movements and the lateral placement of feet during the pivot point when changing direction. If the foot rotates when pivoting, stability is disrupted because of the restricted lateral flexibility of the ankle and knee joint (Sekulic *et al.*, 2013).

Higher degrees of stability can be achieved by leaning forward and lowering the body's centre of gravity, possibly allowing more rapid directional changes (Sheppard & Young, 2006). Thus, appropriate postural adjustments could affect the ability to change direction when in motion. The T-test is suggested to illustrate this hypothesis because of the movement patterns associated with the test (Sekulic *et al.*, 2013). The ability to rapidly accelerate and decelerate in different directions is required to do well in this test. This action could cause perturbations of the body's centre of gravity, thus effective postural control during static or dynamic balance may positively affect CODS.

Lockie *et al.* (2016) are among the few researchers known to explore whether efficient control of posture contributes to CODS. The investigators analysed test data of 26 recreational male athletes from a range of team sports (age=22.88±4.02), to see whether superior dynamic stability performances could differentiate participants between faster and slower CODS times. The time to stability test was used to assess dynamic stability, while COD ability was assessed using the 505-CODS test and the modified T-test. Time to stabilisation was measured on a force plate by assessing the ground reaction forces experienced following a jump landing. The aim of this test is to attain a stable position as quickly as possible on one leg, after jumping a predetermined height. A stable position was attained when the participants' ground reaction forces reach and stay within 5% of their bodyweight. A shorter time to stability is an indication of greater dynamic stability. Results indicated that the faster CODS group did not have superior dynamic stability compared to the slower group. Furthermore, there were no significant correlations found between time to stabilisation and CODS tests. The authors speculate that the lack of a significant difference was due to the nature of the movements of the tasks. They argue that although both tasks require efficient deceleration, the time period of the deceleration phase when changing direction is much shorter than the deceleration which occurs upon landing. Furthermore, in a rapid COD a subsequent acceleration follows the deceleration and directional change. However, no accelerative phase follows the stabilisation period of the drop jump test.

2.3.1.3. LEG MUSCLE QUALITIES

In the deterministic model proposed by Young *et al.* (2002), leg muscle qualities such as reactive strength, concentric strength and power abilities influence the performance of CODS. The suggested model has led to the thorough investigation of the relationship between leg strength and power abilities and CODS abilities (Brughelli *et al.*, 2008; Markovic, 2007; Peterson *et al.*, 2006; Sassi *et al.*, 2009; Sekulic *et al.*, 2013). As seen with the relationship of acceleration ability and COD ability, literature investigating the relationship of leg muscle qualities and COD ability seem to be inconsistent.

These inconsistent results are also likely due to the variation in tests used to assess CODS performance. Studies using CODS assessments over shorter distances and with less direction changes seem to show a stronger relationship than those using longer and more complicated CODS tests. Additionally, the methods and protocols used to determine leg power and strength vary among studies, thus being another probable reason for inconsistent results. Despite the inconsistent findings, the influence of leg muscle qualities on COD ability seems to be more prominent among females than among males. In the studies examined where male and female subjects were used, the female subjects had stronger correlation coefficients than their male counterparts (McFarland, Dawes, Elder & Lockie, 2016; Peterson *et al.*, 2006; Sekulic *et al.*, 2013).

A one repetition maximum squat is often used to measure a participant's strength capabilities (Arin, Jansson & Skarphagen, 2012; Delaney, Scott, Ballard, Duthie, Hickmans, Lockie & Dascombe, 2015; Peterson *et al.*, 2006; Young, Miller, *et al.*, 2015), while other methods such as a leg press have also been used (Arin *et al*., 2012; Jones *et al*., 2009). It has been strongly suggested that strength data should be considered in relation to the bodyweight of the subject (Watts, 2015). The need to assess strength relative to bodyweight is demonstrated in a study by Delaney *et al.* (2015). The results of this study indicated that absolute strength scores were not significantly correlated to the times of a CODS test, however, when relative strength scores were used, the two variables were shown to be moderately correlated to one another (r=-0.52 to -0.56). Despite using relative strength, inverse relationships of varied strengths have been reported among the studies analysed. The range of the strength of the correlation coefficients are small (Young, Miller, *et al.*, 2015) to very large (Spiteri *et al.*, 2014).

Power capabilities are often measured using maximum vertical jump heights from jumping tests, such as the squat jump and the countermovement jump (Brughelli *et al.*, 2008). The strength of the relationship between lower limb power and CODS varies among literature. Some found no significant correlation between the two abilities (Markovic, 2007; McFarland *et al.*, 2016; Peterson *et al.*, 2006; Salaj & Markovic, 2011; Sekulic *et al.*, 2013). Moderate (Jones *et al.*, 2009; Nimphius *et al.*, 2010; Sekulic *et al.*, 2013) to large (McFarland *et al.*, 2016; Vescovi & Mcguigan, 2008) correlations have also been previously reported. Very large correlations have seldom been reported (McFarland *et al.*, 2016; Peterson *et al.*, 2006), however, it is important to note that only female subjects displayed these strong correlations. Sekulic *et al.* (2013) suggest that an explanation for reports of a poor relationship between power and planned COD tests could be due to the rigid nature of the jumping tasks used to assess power. Changing direction while running at speed is a complex motor task. It requires fine coordination of various lower limb muscles, accompanied by synergistic muscular function of the torso and upper limbs (Sekulic *et al.*, 2013).

Reactive strength has been evaluated using the drop jump test (Brughelli *et al.*, 2008; Delaney *et al.*, 2015; Young, Miller, *et al.*, 2015). For this test the participant is required to step off an elevated height (i.e. a box) onto a force-plate and perform a vertical jump upon landing. The objective is to achieve a maximum height as quickly as possible. The height is divided by the ground contact time of the jump to produce a reaction strength index (Delaney *et al.*, 2015; Lockie, Murphy, Knight & Janse de Jong, 2011; Young, Miller, *et al.*, 2015). Therefore, a greater height achieved over a short time period would produce a high score. Studies using this method to assess reactive strength ability have found moderate (Delaney *et al.*, 2015) to large (Young, Miller, *et al.*, 2015) relationships between the two. This aspect of lower limb quality is not frequently assessed; however, future studies are suggested to implement this method of assessing reactive strength. The drop jump test requires a period of deceleration when landing, followed by an explosive movement as quickly as possible. As previously explained, CODS is reliant on similar movement (i.e. controlled deceleration followed by acceleration).

Table 2. 1 Summary of the studies done on athletes to determine the correlations of change of direction, straight-line speed and postural control performance

Study	Population					CODS test	Component & Correlation
	N	Sex	Age	Sport	Playing level		
Arin *et al.* (2012)	20	Male	16.6±1.3	Ice hockey (n=10) Soccer (n=10)	Sport institute (school)	Pro-agility	5m Sprint (r=-0.424) (NS) 10m Sprint (r=0.629) 20m Sprint (r=0.641)
Cuthbert *et al.* (2017)	36	Male	18-22	Rugby union (n=23) Soccer (n=13)	Collegiate level athletes	505-CODS 90° cut	5m Sprint (0.42 to 0.64) 10m Sprint (0.49 to 0.75) 20m Sprint (0.48 to 0.84) CODD (0.48 to 0.77)
Dos'Santos *et al.* (2017)	43	Female	15.4±1.1	Netball	Youth performance academy	505-CODS (ND and D)	10m Sprint (r=0.355 to 0.359) COD deficit (r=0.500 to 0.593)
Gabbett *et al.* (2008)	42	Male	23.65±5.3	Australian rugby league	First grade (n=12) Second grade (n=30)	505-CODS L-run	5m Sprint (r=0.52 - 0.61; p<0.01) 10m Sprint (r=0.57-0.64; p<0.01) 20m Sprint (r=0.58-0.73; p<0.01)
Jones *et al.* (2009)	38	Male (n=35) Female (n=3)	21.5±3.8	University students	NA	505-CODS	5m Sprint (r=0.518; p<0.01)
Köklü *et al.* (2014)	15	Male	16.0±0.8	Soccer	Youth Academy players	Zigzag	10m Sprint (r=0.567) 30m Sprint (r=0.744)
Little & William (2005)	106	Male	18-36	Soccer	Professional (English first & Second division)	Zigzag	10m sprint (r=0.346; p<0.0005)
Lockie *et al.* (2014)	20	Male	22.30±3.97	Basketball	Semi-professional (n=10) Recreational (n=10)	CODST	10m sprint (r=0.590-0.755)
Lockie *et al.* (2016)	26	Male	22.88±4.02	Mixed	Recreational	505-CODS mT-test	Dynamic stability – TTS (r=-0.188 to 0.322)
Nimphius *et al.* (2010)	10	Female	18.1±1.6	Softball	High level (Sport institute players	505-CODS	10m (r=0.53 to 0.96)
Nimphius *et al.* (2013)	66	Male	18-21	American football	Collegiate division 1	Pro-agility	10-yard sprint (r=0.91) COD deficit (r=0.54)
Nimphius *et al.* (2016)	17	Male	24.4±5.0	Cricket	First grade	505-CODS	10m sprint (r=0.58; p<0.05) 30m sprint (r=0.70; p<0.05)

Salaj & Markovic (2011)	87	Male	19.3±1	Mixed	College level athletes	Pro-agility Lateral stepping Figure 8	5m Sprint (r=0.23 to 0.43) 10m Sprint (r=0.19 to 0.32) 20m Sprint (r=0.18 to 0.33)
Sassi *et al.* (2009)	86	Male (n=52) Female (n=34)	22.5±1.5	Mixed (Physical Education university students)	NA	mT-Test	10m sprint - Male (r=0.22) - Female (r=0.34; p<0.05)
Sayers (2015)	15	Male	24.6±4.7	Australian Rugby league	Amateur	505-CODS	5m Sprint (r=0.89; p<0.01) 10m Sprint (r=0.91; p<0.01) - 20m Sprint (r=0.93; p<0.01)
Sekulic *et al.* (2013)	63	Male (n=32) Female (n=31)	20.2±1.89	Mixed	Recreational	T-Test Zigzag test Pro-agility T180 FWDBWD	10m sprint - Male (r=0.11 to 0.77) - Female (r=0.33 to 0.81) 20m sprint - Male (r=0.09 to 0.51) - Female (r=0.31 to 0.55) Overall Stability Index - Male (r=0.15 to 0.58) - Female (r=0.11 to 0.37) Limit of Stability - Male (r=0.01 to -0.47) - Female (r=0.01 to -0.33
Sheppard *et al.* (2006)	38	Male	21.8±3.2	Australian rules football	High performance (n=24) Lower performance (n=14)	CODST	10m Sprint (r=0.738)
Vescovi *et al.* (2008)	140	Female	19-23	Soccer (n=51) Lacrosse (n=79)	College Division 1	Modified Illinois test Pro-agility	9.1m Sprint (r=0.533 to 0.671) 18.2m Sprint (r=0.612 to 0.753) 27.3m Sprint (r=0.628 to 0.795) 36.6m Sprint (r=0.590 to 0.831)
Young *et al.* (2015)	24	Male	18-24	Australian rules football	Community level	CODST	10m sprint (r=0.510; p<0.05)

2.3.2. TESTS ASSESSING CHANGE OF DIRECTION SPEED

A variety of field tests have been developed and adopted by coaches to assess an athlete's directional change ability. Each test is developed to include game or even position specific movement patterns. CODS tests differ in a few features such as the duration, amount of directional changes, angles of directional change and total distance covered.

In a review by Young *et al.* (2015), the authors suggest there is no "gold-standard" generic CODS field test developed for invasion sports. This statement is based on results from a study by Sporis *et al.* (2010), which compared the performance of six different CODS tests to one another. The following tests were used by Sporis *et al.* (2010): T-test, slalom run, S4x5, S90°, S180° and the S180° with backward runs. Trivial to moderate inter-correlations ranging from -0.028 to 0.544 were reported. The researchers concluded each CODS was specific due to complexities of each test and the different movement patterns applied in them. However, a different study revealed strong correlations between the five CODS tests assessed in their study (Stewart, Turner & Miller, 2014). The following tests were assessed by Stewart *et al.* (2014): T-test, Illinois run, L-run, pro-agility and 505-CODS test. The inter-correlations ranged from 0.84 to 0.89. Considering this, Stewart *et al*. (2012) concluded that all the tests assessed the general athletic ability to change direction. It must be noted that the T-test was the only test used in both studies. This could suggest that the other tests used in the study by Sporis *et al.* (2010) were specifically suited for certain soccer positions.

Table 2.2 summarises the details of CODS tests that are frequently used in various invasive team sports. Some authors recommend that CODS tests should be categorised according to certain characteristics of the test, such as the time taken to complete the test and the amount of directional changes (Bourgeois, 2017; Brughelli *et al.*, 2008). The categories of time to completion were classified as 0-5s, 5-9s and ≥10s. The categories of amount of directional changes was specified as 1-3 COD, 4-6 COD and ≥7 COD.

Nimphius *et al.* (2013) argue that many of the CODS tests that are regularly used fail to accurately isolate and assess an athlete's ability to both decelerate and reaccelerate toward a predetermined direction. The characteristics of the test could cause other physical components to play a role in the performance, therefore dampening the emphasis on CODS ability (Brughelli, Cronin & Chaouachi, 2011; Nimphius *et al.*, 2017; Sayers, 2015; Vescovi & Mcguigan, 2008). Anaerobic metabolism is generally regarded as the primary energy system used during a CODS assessment (Brughelli *et al.*, 2008). However, the characteristics of certain complicated testing protocols has led some authors to question whether these types of tests are affected by an individual's aerobic fitness (Brughelli *et al.*, 2008; Nimphius *et al.*, 2017; Sayers, 2015). For example, the Illinois agility run takes an estimated 13-19s, which includes 11 turns over an estimated distance of 60m. Another criticism aimed at a number of the existing CODS tests, is that many of these performances rely on an athlete's manoeuvrability (Nimphius *et al.*, 2017). Directional changes during a curvilinear path require velocity to be maintained. In contrast, directional changes at greater angles (e.g. 180°) require a period of rapid deceleration to change direction, followed by acceleration to the set direction.

A test which appears to restrict many of these limitations is the 505-CODS test. Although originally developed to simulate directional change experienced by a batsman in cricket, it is used in a variety of sports to assess CODS (Barber *et al.*, 2015). The traditional 505-CODS test requires timing gates to be placed 5m from a designated turning line. Athletes assume a stationary starting position 10m from the starting gates, thus 15m away from the turning point. On own command, athletes are required to accelerate past the timing gates, reach and pivot 180° on the turning line with a single leg, and finally accelerate back to the timing gates. The change of direction ability of both legs can be assessed by repeating the test and pivoting on the opposite leg. The duration and the distance covered in the test is low relative to other popular CODS tests, hence greater emphasis is placed on an athlete's actual CODS ability (Nimphius *et al.*, 2016).

Despite the attempted exclusion of limitations present in many other CODS tests, Sayers (2015) suggests that the 505-CODS may still not be focusing on an athlete's directional change ability. Acceleration ability remains an influence in the time recorded for the 505-CODS test (Nimphius *et al.*, 2013; Sayers, 2015), thus CODS ability is not properly isolated. This inconsistency is highlighted in a study by Nimphius *et al.* (2013) which found that the time spent actually changing direction in the 505-CODS is less than a third of the total recorded time. Therefore, it is possible that acceleration or SLS ability could still mask CODS ability in a test such as the 505-CODS test.

Sayers (2015) suggests that CODS should be measured over even shorter distances to reduce acceleration ability's masked effect on CODS. Using 15 amateur level Australian rugby league players as participants (age=24.6±4.7), the researchers compared the relationship between their SLS times and the CODS times recorded over various distances. The CODS test used was the 505-CODS test, while the time was also recorded at points closer to the directional change. These distances were 0.3m, 0.5m and 1m away from the turning line. The author reported proportionally weaker correlations between CODS and linear running ability for CODS test distances less than one metre. The traditional 505-CODS test displayed a very large to near perfect correlation to the sprinting times at the 5m, 10m and 20m points (r=0.89 to 0.93), whereas the test where the CODS time was recorded at the 0.3m mark had the lowest correlation to the acceleration times (r=0.50 to 0.58). However, this approach would be unpractical for a field-based test. The lean while changing direction could trigger the laser of the timing gates prematurely (Nimphius *et al.*, 2016). This is also evident in the same study by Sayers (2015) which found that the reliability of the times decreased when testing distances were reduced.

A more practical solution to eliminating the influence that acceleration ability has on CODS tests, is the COD deficit proposed by Nimphius, Geib, Spiteri and Carlisle (2013). This method of assessing COD ability is relatively new. To our knowledge, the COD deficit has only been used in a limited amount of studies (Cuthbert *et al.*, 2017; Dos'Santos *et al.*, 2018; Loturco *et al.*, 2018; Nimphius *et al.*, 2016, 2013; Pereira, Nimphius, Kobal, Kitamura, Turisco, Orsi, Cal Abad & Loturco, 2018). In the next sub-section, the COD deficit and the findings of some of these studies using this method will be discussed in detail.

Table 2. 2 Summary of tests typically used to assess CODS in team sports

CODS test	Amount of COD	Distance of test (m)	Estimated duration (s)	Estimated angle of COD	Study used in
505-CODS	1	10	1.5-3	180°	Delaney *et al.* (2015); Dos'Santos *et al.* (2017); Gabbett *et al.* (2008); Jones *et al.* (2008); Lockie *et al.* (2016) Nimphius *et al.* (2010); Nimphius *et al.* (2016); Sayers (2015); Spiteri *et al.* (2014); Stewart *et al.* (2014)
Y-agility test	1	10	2-3	45°	Lockie *et al.* (2014); Young *et al.* (2015)
COD speed test	1	8	1.5-2	45°	Sheppard *et al.* (2006)
Pro-agility *or* 20-yard shuttle	2	18.28	4-5.5	180°	Arin *et al.* (2012); Markovic (2007); Nimphius *et al.* (2013); Sekulic *et al.* (2013); Salaj & Markovic (2011); Stewart *et al.* (2014); Vescovi (2008)
Zigzag	3	20[a]	6-7	100°	Köklü *et al.* (2014); Little & William (2005); Sekulic *et al.* (2013)
Sprint 4 x 5 (S4x5)	3	20	5-7	90°, 180°	Sporis *et al.* (2010)
CODAT	4	24[a]	5-7	45°, 90°	Lockie *et al.* (2013); Lockie *et al.* (2013)
Modified T-test	4	20	6-8	90°	Sassi *et al.* (2009); Lockie *et al.* (2017)
Sprint 9-3-6-3-9 with 180° turns (S180)	4	33	6-8	180°	Sporis *et al.* (2010)
T-test	4	36.56	10-12	90°	Lockie *et al.* (2013); Peterson *et al.* (2006); Sekulic *et al.* (2013); Spiteri *et al.* (2014); Sporis *et al.* (2010); Stewart *et al.* (2014)
L-run *or* 3 cone drill	5	27.4[a]	7-8	90°, 180°	Gabbett *et al.* (2008); Stewart *et al.* (2014)
Lateral stepping	5	24	7-9	180°	Markovic (2007); Salaj & Markovic (2011)
Agility test with 180° turns (T180)	5	30	8-10	180°	Sekulic *et al.* (2013)
Forward-backward run agility test (FWDBWD)	5	30	8-10	180°	Sekulic *et al.* (2013)
Figure 8	6	24[a]	11-13	180°	Salaj & Markovic (2011)
Modified Illinois	9	42[a]	9-11	90°, 180°	Vescovi *et al.* (2008)
Illinois agility run	11	60[a]	13-19	90°, 180°	Lockie *et al.* (2013); Sheppard & Young (2006); Stewart *et al.* (2014)
Slalom run	11	22[a]	7-14	90°, 180°	Markovic (2007); Sporis *et al.* (2010)

[a] Indicates that the test requires turns around cones (or poles), therefore the distance provided is based on the linear distances between cones (or poles), however, the actual distance covered is dependent on the athlete's path or trajectory

2.3.2.1. THE CHANGE OF DIRECTION DEFICIT

The COD deficit was designed as a more practical way to isolate the athletic ability of changing direction. This could assist coaches and practitioners in keeping track of any progress in improving COD ability (or lack thereof) without the additional time and cost that comes with a gold-standard laboratory assessment. The COD deficit is calculated by subtracting the time of a SLS test from the total time that a CODS test of equal overall distance took. The lower the deficit, the more effective an athlete is at changing direction relative to their sprinting capabilities (Dos'Santos *et al.*, 2018; Loturco *et al.*, 2018; Nimphius *et al.*, 2016, 2013). Therefore, instead of sprinting ability being inclusive to performance as seen with using total time, the ability of actually changing direction is emphasised.

In the study where this method of assessing CODS ability was first used (Nimphius *et al.*, 2013), the participants were 66 Collegiate Division 1 American football players between the ages of 18 and 22 years. The CODS test used was the pro-agility test, also known as the 20-yard shuttle test. This test involves a 5-yard (4.57m) dash to a turning-point, where a 180° COD is done after which the participant reaccelerates into another dash of 10-yards (9.14m) (passing the starting point), followed by a second 180° COD and then a final 5-yard dash to the timing gates at the starting-point. In this study, the split time of the first passing of the timing gates after the first COD was also recorded. Additionally, a 40-yard (36.58m) sprint test was conducted, which included a 10-yard (9.14m) split time. The COD deficit was calculated as the difference between the first half of the pro-agility time and the 10-yard split time of the sprint. The results show that the COD deficit had a small non-significant correlation to the SLS time ($r=0.19$). In contrast, the full pro-agility test and the pro-agility test at the halfway point had near perfect and large correlation coefficients for the acceleration performances ($r=0.91$ and 0.89). The COD deficit displayed a moderate relationship with regards to pro-agility time over the full test and the halfway-split time ($r=0.54$ and 0.61 respectively). Furthermore, by using the COD deficit as the estimated time that a single directional change takes, the researchers calculated that the actual time taken in the test to change direction was around 31% of the total time of the test. These results demonstrate the skewing effect that acceleration ability can have on a traditional CODS test such as the pro-agility test.

Although COD deficit was originally calculated using the pro-agility test, recent studies have adopted this method to other COD tests. The straightforward process of determining the COD deficit makes it possible to use this method with any desired CODS test, as long as the sprinting time over the same distance is available. Three studies have used the 505-CODS test to calculate the COD deficit (Cuthbert *et al.*, 2017; Dos'Santos *et al.*, 2018; Nimphius *et al.*, 2016). The COD deficit has even been used on a more complicated sport-specific test such as the zigzag COD test, using male soccer players (Loturco *et al.*, 2018) in one test, while male and female Olympic handball players were used in another study (Pereira *et al.*, 2018).

For the relevance of the current study, only the methods and results of the studies using a single turn CODS test to determine the COD deficit, will be discussed in detail. The zigzag CODS test requires two additional directional changes as well as almost double the total distance when compared to the 505-CODS test. Furthermore, the layout of the zigzag test involves direction changes of around 100° allowing some manouvariblity during the COD. To our understanding, these charataristics of the zigzag test could play a role in the degree to which the COD ability is isolated when the COD deficit is used with this test. It is advised that future research explore the effectiveness of the COD deficit with regards to tests involving more than one COD.

The one study using the 505-CODS test to calculate the COD deficit was conducted by some of the same researchers involved in the original study where this method was first used (Nimphius *et al.*, 2016). The participants in the study were 17 experienced male cricket players (age=24.4±5 years) competing in an Australian regional competition. The purpose of the study was to determine the relationship between linear speed, 505-CODS times and the proposed COD deficit. Three trials of 30m sprints and 505-CODS, turning of both the left and right foot, were performed by the participants. The average times of the three trials were used for analysis. Researchers found a large to very large correlation between 505-CODS time and linear speed over 10m and 20m (r=0.58 and r=0.70; respectively). In contrast, there was no correlation between the COD deficit and SLS times, while the 505-CODS time and COD deficit had the strongest correlation (r=0.74). The authors conclude that these results suggest that the COD deficit score is a more isolated indication of the ability to change direction at high speeds. They argue that the absence of a relationship between the COD deficit and SLS times suggests that the physical capacity of linear speed is eliminated when using the COD deficit. Furthermore, the strong correlation of COD deficit and the 505-CODS time suggests that the same variable (i.e. COD while at speed) is still being evaluated. As previously mentioned, this is a relatively new and unexplored method of assessing COD ability. The authors have recommended that other researchers explore using this method among other populations to confirm its validity.

In a recent study by Dos'Santos *et al.* (2018), the COD deficit was used to assess the CODS abilities of academy youth female netball players (age=15.4±1.1). To our knowledge, this is currently the only study assessing COD ability using the COD deficit on female subjects. Similar to previous studies, this study also investigated the relationship that COD deficit has with SLS ability and the original CODS test used. The CODS test which was used to assess COD ability was the 505-CODS test; therefore, the time of a 10m SLS was appropriately also recorded. In contrast to the results reported in both articles by Nimphius *et al.* (2013; 2016), large inverse relationships were observed between the COD deficit and the 10m sprint times (r=-0.539 to -0.633). These results indicate that the netball players with high straight-line sprint abilities obtained high COD deficit scores, thus indicating poor COD abilities. The researchers conclude that this group of athletes may not have the capabilities to rapidly decelerate, change direction and reaccelerate from a high entry speed 180° turn.

While this conclusion may be true, the fact that it is the first occasion where only female athletes were used to assess COD deficit should not be ignored. As expressed earlier, the weight of the relationship of other performance factors on COD ability seems to be gender-specific. In studies with male and female participants, where the total time of a CODS test was used to assess CODS ability, the relationship between CODS ability and acceleration ability was more prominent among female participants than their male counterparts (Sassi *et al.*, 2009; Sekulic *et al.*, 2013). These types of findings suggest that females rely (more than males) on acceleration ability to perform well in CODS tests which use total time of the test. This could be a probable explanation for the inverse correlation found among the female netball players in the study by Dos'Santos *et al*. (2018). By assessing CODS ability as the total time to complete a CODS test, the players with fast acceleration abilities are perceived to perform better than slower participants. However, by eliminating the influence of acceleration performance from the COD deficit reveals that the faster netball players took longer to transition from a deceleration to subsequent acceleration after a 180° direction change.

Another suggested advantage of using the COD deficit is its ability to clearly identify asymmetries in CODS ability between limbs. In the study by Dos'Santos *et al*. (2018) using youth academy female netball players, asymmetries in CODS performances were quantified via the COD deficit, as well as the completion time of a CODS test. The results indicated significant differences in CODS performances between turning with the dominant and the non-dominant limb. This result was the same for both the COD deficit and the 505-CODS time. However, quantified as a percentage, substantially greater asymmetries for COD deficit were observed compared to the 505-CODS time. Using the COD deficit indicated a mean asymmetry of 11.9%, whereas the 505-CODS time showed an imbalance of 2.3%. By eliminating the masking effect of acceleration ability, larger percentage imbalances between limbs could be identified. This can be helpful to practitioners as large symmetries between legs could indicate a deficiency in the turning ability to a specific direction which could subsequently influence future training (Dos'Santos *et al.*, 2018).

2.3.3. CHANGE OF DIRECTION SPEED SUMMARY

In many invasion type team sports, agility is regarded as a highly sought-after bio-motor ability to measure and assess among coaches and researchers. For a long time, the generally accepted definitions of agility only addressed the rapid directional change which takes place in the movement. Therefore, the perceptual and decision-making factors which would exist in response to the actions of an opponent were not considered. This caused many performance tests designed to assess agility performance to also exclude these factors. More recent definitions and assessments of agility take the perceptual and decision-making factors into account; thus, many researchers agree that agility performance is dependent on both physical and cognitive factors.

Tests which only assess the ability to rapidly change direction in a pre-planned direction are now understood to measure CODS ability. Determining the underlying physical factors which affect CODS ability has been thoroughly researched. Many recent studies examine the relationship that physical factors such as acceleration, lower-limb muscle qualities and postural control have on planned CODS performance. Despite this there seems to be inconsistent findings regarding how much each underlying physical factor is believed to affect CODS performance. However, research does show that gender could have an influence on the strength of the relationship. Explosive factors such as acceleration and power seem to have a larger impact on performance among women compared to men.

Close examination of the studies investigating these types of relationships reveal that a wide variety of CODS tests were used across the literature researched. These various CODS tests used in previous studies have differing characteristics; such as the distance of the test, the estimated duration of the test, the number of directional changes and the angle of directional change. There does not seem to be a universally agreed upon field-based performance test which assesses CODS ability. This could be a potential reason for the inconsistent findings in current research. Furthermore, the characteristics of some of the existing planned CODS tests could potentially cause other physical factors (e.g. acceleration ability or aerobic capacity) to influence overall performance. Thus, the ability to change direction is not isolated in many of the commonly used tests. This has led to new methods of assessing CODS being developed.

The COD deficit is a proposed method to assess an individual's ability to change direction while at speed. The COD deficit is calculated by subtracting the time taken in a straight-line sprint, from a CODS of equal overall testing distance. This method could potentially help eliminate the influence of acceleration ability, thus giving a clearer indication of COD ability. Furthermore, the COD deficit could be used by coaches to assess imbalances in CODS performances between dominant and non-dominant sides.

The COD deficit is a relatively novel method of assessing CODS ability. This study aims to add to the currently limited literature to aid future researchers who wish to further investigate the use of the COD deficit. It is important for a performance test to effectively assess a specific bio-motor ability which it was designed to, with minimal influence from other bio-motor abilities.

Further investigation of the 505-CODS test and the COD deficit and their respective correlations with acceleration ability could assist in providing support to the claim that the COD deficit is an isolated measure of assessing CODS ability.

2.4. STRAIGHT-LINE SPEED AND SPATIOTEMPORAL GAIT VARIABLES

Maximal velocity efforts may only contribute a small fraction of the overall distance covered during matches in invasive team sports, however, they can be crucial to gaining many match winning opportunities (Chandler *et al.*, 2014; Davidson & Trewartha, 2008; Little & Williams, 2005). Being able to move at a greater speed could help a player to get into the right area to make an interception or to create scoring chances. Most sprints that occur in invasion sports such as netball are over short distances and rarely exceed much more than two seconds (Chandler *et al.*, 2014; Davidson & Trewartha, 2008; Fox *et al.*, 2013). This highlights the importance of acceleration, which is better defined as the ability to attain a high running velocity in as short a time or distance as possible (Lockie, Murphy, Schultz, Jeffriess & Callaghan, 2013).

Most studies investigating the determents of acceleration performance use sprinting track athletes. The acceleration phase among experienced sprinters in a 100m race has previously been reported to be the first 30m (Debaere *et al.*, 2013). It must be kept in mind that track acceleration or speed is different to invasion team sports acceleration or speed. Due to the shorter sprinting distances, athletes competing in invasion types of sports have been suggested to achieve maximal velocity in a shorter distance compared to track athletes (Hewit *et al.*, 2013).

Typically researched spatiotemporal gait variables include stride frequency (SF), stride length (SL), flight time (FT) and ground contact time (GCT) (Hewit *et al.*, 2013; Lockie *et al.*, 2011; Lockie, Murphy, *et al.*, 2013; Murphy, 2017). SF refers to the number of steps made per second from both feet. SL is the distance covered from where one foot makes contact with the ground until the same foot makes contact again, thus involving both the stance and swing phase of that leg. GCT is the amount of time the stance phase takes from initial contact till toe-off; while FT is the duration of the floating phase from toe-off of one leg until the foot strike of the other leg. FT signifies the time it takes to reposition the leg in the air for the following step. These variables have been investigated to identify their influence on sprinting performance (Lockie *et al.*, 2011; Lockie, Murphy, *et al.*, 2013; Nummela, Keränen & Mikkelsson, 2007). SL and SF have been of particular interest in research due to the proposed sprint formula. This formula states that average speed is a product of SL and SF (Fletcher, 2009). Components such as GCT and FT directly affect the SL and SF (Lockie *et al.*, 2011).

Nummela *et al.* (2007) investigated the relationship between sprinting mechanics and running speed among 25 male endurance runners (age=19.8±1.1). The results revealed a large significant inverse correlation between GCT and the maximal velocity attained over a 30m SLS distance (r=-0.52). Therefore, a quick GCT was associated with a fast SLS performance. A similar finding was reported by Lockie *et al.* (2011). The researchers investigated factors differentiating faster and slower field sport athletes. Twenty male active field sport athletes (age=21.9±2.9) were split into a faster and slower group according to their average velocity over ten meters. The relationship between step kinematics and velocities reached over a 10m straight-line sprint were investigated. The key finding from this study was that GCT was the main spatiotemporal variable which demarcated the faster athletes from the slower athletes. Results showed that contact times for the faster group were ¬16% shorter over 5m and ¬11% shorter over 10m, compared to the slower group. SL and SF did not significantly distinguish the two groups from one another.

This finding of shorter contact times being correlated to running faster velocities was supported in a similar study by the same author, also on male field sport athletes (N=22; age=22.6±3.2) (Lockie, Murphy, *et al.*, 2013). Additionally, results of this study showed significant relationships between SL and velocity at 0 to 5m and 0 to 10m (r=0.397-0.535). The faster field sport athletes displayed longer SL compared to their slower counterparts. Along with the increased SL, longer FT was also seen with the faster athletes due to FT being a function of SL (Lockie *et al*., 2013). The researchers suggest that the shorter GCT and longer SL among faster athletes could indicate that they are able to generate force more efficiently to propel them over a longer distance. During the sprinting cycle, the contact phase is the only phase in which force can be produced to influence SL and sprinting speed (Nummela *et al.*, 2007).

2.5. POSTURAL CONTROL

In this section an in-depth explanation of postural control and the resources which govern it will be discussed. Following this, a background will be given of the tests and equipment used to measure postural control. Finally, the relevance that this ability has toward sport will be mentioned, as well as how its improvement is believed to assist athletes.

Horak (2006; p10) defines postural control as “a complex skill based on the interaction of dynamic sensorimotor processes”. Postural control has two functional goals: (1) Postural orientation and (2) Postural equilibrium (Horak, 2006). Postural orientation involves the controlled alignment of the head and the trunk with regards to internal references, visual cues, the support surface, and gravity. Interpreting the changes in the external environment requires adequate processing of the incoming sensory information from visual, vestibular and somatosensory systems. The relative amount of reliance on each specific sensory input depends on the environmental surroundings and the goals of the movement task required. Attaining postural equilibrium involves coordinated sensorimotor strategies to maintain control of the body’s centre of mass over the body’s base of support, i.e. the feet. The stabilisation of the centre of mass should be maintained during both self-initiated and externally activated disturbances in postural stability.

Postural control can be divided into two subcategories: static and dynamic postural control. Static postural control is the ability to maintain a stable base of support with minimal sway or movement, while dynamic postural control is the ability to retain control of posture following a perturbation or during movement (Chander, MacDonald, Dabbs, Allen, Lamont & Garner, 2014).

To better understand postural control, it is important to consider the different physiological systems which are at work and what contributions they add to maintain the correct postural orientation and postural equilibrium. Understanding these systems makes it possible to predict situations where specific individuals are at a greater risk of falling. For example, an underdeveloped vestibular system could result in an increased risk of falling when in the dark.

Horak (2006) notes that there are six important resources required to maintain postural control: biomechanical constraints, movement strategies, sensory strategies, orientation in space, control of dynamics and cognitive processing. Impairment in any one or more of these subcomponents of the postural system would lead to postural instability.

The first resource mentioned is biomechanical constraints. To maintain postural equilibrium, it is important that the body's centre of mass is controlled over the body's base of support. The degree to which an individual can maintain control of the centre of mass is highly dependent on factors relating to the condition of the feet. During bipedal stance, there is a cone shaped area through which an individual can move while maintaining postural equilibrium without changing the base of support (Horak, 2006). The perimeter of this cone area is known as the 'Limit of Stability' (LOS) (Nashner, 2010; Sekulic *et al.*, 2013). Nashner (2010) notes that the positioning of the body's centre of mass during stance or walking is influenced by the relative position of the head, arms, hips, knees and ankles.

When postural equilibrium is compromised, there are three types of movement strategies that can be used to restore equilibrium. These strategies include the ankle strategy, the hip strategy and the step strategy. The ankle and hip strategies keep the feet in the same place while the step strategy requires an individual to change the base of support (Horak, 2006; Nashner, 2010). During the ankle strategy, the centre of mass moves as a flexible inverted pendulum around the ankle. This strategy is done on a firm surface that allows slow and controlled movements within the LOS. The hip strategy is used when an individual stands on a narrow or an unstable surface. This strategy requires the body to quickly rotate around the hips to create a moment of inertia at the trunk. The trunk then accelerates into one direction so that a horizontal shear force against the base of support causes the centre of mass to move into the opposite direction (Nashner, 2010).

To keep track of the positioning of the centre of mass in relation to the base of support a combination of visual, vestibular and somatosensory inputs are required (Nashner, 2010). Visual inputs are responsible for the position and movement of the head in relation to the surrounding environment, which is important for maintaining postural orientation (Hammami *et al.*, 2014). The vestibular system senses angular and linear accelerations which act on the body as a whole (Golshaei, 2013). Somatosensory input is responsible for directly perceiving the external environment (i.e. proprioception) and determining location and velocity of the body parts (Golshaei, 2013). The integration of these signals is referred to the sensory strategy. As the sensory environment is changed, the dependence of each sensory input is reweighted. For example, standing on an unstable support surface would require increased sensory weighting of visual and vestibular inputs.

Another important resource is orientation of space. A vital component of postural control would be the capability to correctly orientate body parts and the centre of mass with regards to visual cues, gravity, the support base as well as internal references. A healthy nervous system is meant to make automatic alterations of the body's orientation in space according to the context of the task at hand. To maintain balance while undergoing a change in posture requires a controlled movement of the body's centre of mass. This resource can be described as control of dynamics. When stability is compromised, an individual must readjust his body or limbs to support the centre of mass. Complex postural tasks require an increased amount of cognitive processing to maintain postural control. Maintaining stability could become more challenging when responding to commands during a task or while attending to another task (Sibley, Beauchamp, Ooteghem, Straus & Jaglal, 2015).

Based on the description of these six resources, maintaining stable postural control can also be described as the product of internal sensory inputs and the body as a mechanical system which interacts with the central nervous system in an ever changing environment (Sibley *et al.*, 2015). Control and efficient management of the resources mentioned make it possible to maintain and/or retain adequate control of posture when stability is challenged. Moments of instability and falls during static and dynamic situations can be minimised if these resources are improved.

2.5.1. TESTING POSTURAL CONTROL

Previously, the most widely used way to evaluate postural control by clinicians was to use clinical rating scales which have several limitations such as poor reliability, a clinician's biased and subjective view, and the insensitivity to mild impairments (Mancini, Salarian, Carlson-Kuhta, Zampieri, King, Chiari & Horak, 2012). The combination of improvement in understanding postural control and the advancement in technology has resulted in the development of new assessment tools which allows postural control to be evaluated. These assessments are usually used in clinical situations where changes in postural control over time are recorded in patients with head injuries, older adults or in patients who have neurological disorders such as Parkinson's disease (Mancini *et al*., 2012). However, the assessment of postural control is becoming increasingly popular among researchers investigating the enhancement of postural control from participating in physical activity (Fong, Tsang & Ng, 2012) and the effect postural control has on selected sporting performance parameters (Sekulic *et al.*, 2013).

The most commonly used technological options which are applied to evaluate postural control are computerised dynamic posturography (CDP) and force plates (Fong *et al.*, 2012; Mancini *et al.*, 2012; Nashner, 2010; Whitney, Roche, Marchetti, Lin, Steed, Furman, Musolino & Redfern, 2011). By being exposed to a series of specific conditions, it is possible to isolate the sensory effects that visual, somatosensory and vestibular inputs have on maintaining postural control during stance. This makes it possible to identify how much reliance is placed on each sensory system to maintain postural stability. The modified clinical test for sensory interaction on balance (mCTSIB) protocol has previously been used to isolate these sensory inputs (Hammami *et al.*, 2014). The mCTSIB protocol consists of four conditions: 1) standing on a firm surface with opened eyes; 2) standing on a firm surface with closed eyes; 3) standing on a foam surface with opened eyes; 4) standing on a foam surface with closed eyes. The investigation of the amount of sway present during a specific condition can give an indication of how reliant an athlete is on a specific sensory input to maintain control of posture. For example, if an athlete is dependent on visual inputs to maintain balance there will be more sway present in the conditions where the eyes are closed.

Using this CDP and force plates to assess postural control have been proven to be helpful in a clinical setting to identify impairments making a person more prone to falls (Mancini *et al.*, 2012; Whitney *et al.*, 2011). However, these testing options are highly expensive as well as immobile. This has led to the need to develop a cheap and mobile technological option. Additionally, it has been suggested that measuring the change in centre of pressure to assess postural control is flawed (Visser, Carpenter, Kooij & Bloem, 2008; Whitney *et al.*, 2011). Using the changes of COP to measure postural control is reliant on the assumption that the motion of the COP is directly proportional to the movement of the centre of mass, which is not the case when different balance strategies are employed (Visser *et al.*, 2008). Accelerometery has been used as an alternative to force plates and CDP machines. Attaching an accelerometer around the waist at the lower lumbar area is suggested to be a more accurate approximation of the displacement in centre of mass (Whitney *et al.*, 2011). This is proposed to be due to the acceleration and orientation of the pelvis being measured.

Whitney and colleagues (2011) compared the balance scores obtained from a CDP machine to the scores obtained from accelerometery using the same sensory organisation test (SOT) protocol. The participants in this study were eighty-one (n=81) healthy subjects aged 19-85 years old who had no known orthopaedic or vestibular deficiencies. The protocol used to isolate each sensory system in this particular study is called the sensory organisation test (SOT). The first three conditions are performed on a fixed support surface with opened eyes in a steady visual surround (1st condition), closed eyes (2nd condition) and eyes open on a sway-referenced visual surrounding (3rd condition). These visual conditions are repeated in the same order for conditions four to six, however taking place on a sway-referenced support surface. 'Sway-referenced' refers to the tilting of the support surface and/or visual target around an axis co-linear with the ankle (Fong *et al.*, 2012). The participant must attempt to stay as still as possible in each described condition, for 20 seconds.

The participants were required to complete three trials of the extended SOT protocol with both the accelerometer and the CDP machine. The results indicated that there was a close correlation across all the SOT conditions between the acceleration measured at the pelvis and the centre of pressure measurements. The test-retest reliability from the accelerometer measures were found to be as good as or better than the COP in almost every SOT condition. Whitney *et al.* (2011) suggest that one trial using accelerometery is sufficient in measuring postural sway, especially in conditions 3, 4 and 5 of the SOT protocol where the most sway is present. This means that the recordings were consistent, thus no repetition is required which could lead to fatigue or learning effects. Improved efficiency would suggest that less time is required to measure sway in a clinical setting. Although CDP and force plates are the more frequently used options, the results from this study suggest that there is a disagreement on what the gold standard is to measure postural control.

2.5.2. POSTURAL CONTROL'S RELEVANCE IN SPORT

Maintaining postural control while in a static or dynamic environment is a vital component to successfully perform a sport specific motor task during training or competition. Achieving the desired sport specific motor skill requires control of the displacement of the centre of mass by making use of the resources required for postural stability and orientation. Improving a single or a combination of the six resources (described earlier) could result in an improvement in postural control and therefore an improvement of sport specific motor tasks.

Prior experience to a sport specific situation would influence the movement strategy deployed to maintain control of the centre of mass. When a disturbance in stability is anticipated, adjustments in posture occur before stability is compromised so that postural equilibrium is maintained (Horak, 2006; Nashner, 2010). Repetitive sport specific balance exercises have been suggested to improve balance ability by relying less on one specific resource of postural control and rely more on another resource (Chapman, Needham, Allison, Lay & Edwards, 2008). For example, neurological adaptations could take place over time, which allows a netball player to be more reliant on somatosensory feedback to maintain postural control during a landing movement, opposed to being reliant on visual inputs. This allows the individual to use visual feedback more efficiently for other tasks, such as planning where to pass the ball after landing.

Paillard and Noé (2006) investigated the contribution that visual inputs have on postural control on soccer players (n=30; age=18-30) across different performance levels. Players were divided into an amateur group, consisting of regional-level players, and a professional group, consisting of national-level players. Postural control was evaluated by a force platform measuring the COP during bipedal stance. Participants were instructed to remain as still as possible for 51.2s, with eyes open for one trial and eyes closed for the other trial. The amount of postural sway was calculated by the total COP displacement divided by the time of the test, reported as COP velocity. Upon analysis of the results, the researchers found that the professional players displayed better postural control scores in both eyes open and eyes closed bipedal conditions. Amateur soccer players displayed more than double the amount of average COP velocity during both testing conditions, compared to the professional group. These results would suggest that because of vigorous training, professional soccer players become less dependent on vision to maintain adequate postural control. This could allow these players to dedicate their vision to other important game type scenarios.

A study by Salaj *et al.* (2007) investigated what effect proprioceptive training would have on tests – vertical jump and agility tests - which assess speed explosiveness abilities. A total of 75 physically active young men (age= 19±1.2 years) were divided into a control group (n=38) and an experimental group (n=37). The experimental group underwent a ten-week proprioceptive training programme, which was repeated three times. The exercises consisted of various single-leg and double-leg static and dynamic drills, where the demands and durations of the exercises increased exponentially. The control group continued their regular daily activities without following a set training regime. A series of explosive jumping and agility tests were performed before and after the ten-week balance training intervention.

The researchers postulated that the proprioceptive training would advance the activity of the neuromuscular system. Proprioception training is believed to improve body awareness due to the improvement in the sense of positioning and the movement of joints, thus body posture and balance would be improved (Salaj, Milanovic & Jukic, 2007). The proprioceptive training caused a significant improvement for the double-leg vertical jump explosive strength test and the 20-yard agility test which tested forward agility. Hrysomallis (2007) suggests that it is unclear to identify what portion of the improvements were due to the actual improvements in balance ability opposed to an amplified training volume which comes with the inclusion of balance training. Kean *et al.* (2006) propose that improved performance measures acquired with the improvement of balance, results in a decreased amount of muscles required to maintain a stable base of support, therefore allowing them to contribute more to force production.

2.5.3. POSTURAL CONTROL SUMMARY

In this section a detailed background of the complex bio-motor ability of postural control (PC) is explained to illustrate the important role that this ability plays in everyday life, and on the sporting field. PC can be defined as a complex skill based on the interaction of dynamic sensorimotor processes which has two functional goals; maintaining postural orientation and postural equilibrium. The complex nature of PC has been suggested to be reliant on the combined effort of six resources to maintain structure; biomechanical constraints, movement strategies, sensory strategies, orientation in space, control of dynamics and cognitive processing. Due to many resources influencing PC ability it is difficult to assess an athlete's overall PC ability by means of a single test. Furthermore, to the researcher's knowledge the ISway PC system has not been used on an athletic population. Previous research using this accelerometery system assessed Parkinson's disease patients. This study aims to add data to literature to aid future researchers who whish to explore this devices effectiveness of assessing PC among athletic populations.

2.6. NETBALL

Netball is a popular team sport which is predominantly played by women among the Commonwealth nations (Thomas, Comfort, *et al.*, 2017). The sport is played in over 70 countries by more than 20 million people (Hetherington, King, Visentin & Bird, 2009). It is played by seven players a side on a 30.5m x 15.25m hard surfaced rectangular court with a round ball. Netball consists of four 15-minute long quarters. The aim of the game is to score more goals than the opponent by shooting the ball into a round goal ring. Players are not permitted to run with the ball and they are required to pass or shoot within three seconds of attaining possession. A variety of jumps, rapid changes of direction, shuffling and short sprints are observed in netball (Fox *et al.*, 2013). These are comparable to movements observed in basketball.

Each position is restricted to certain areas of the court depending on their playing position or role. Additionally, goals can only be scored by certain players in a specific area of the court. The seven positions can be divided into three categories: defenders, centre court and shooters (Thomas, Comfort, *et al.*, 2017). Positions classified as defenders include goal keeper (GK) and goal defence (GD). Mid-court positions include centre (C), wing attack (WA) and wing defence (WD). Finally, positions classified as shooters include goal attack (GA) and goal shooter (GS). Figure 2.2 displays a layout of the positions in their typical areas of the court.

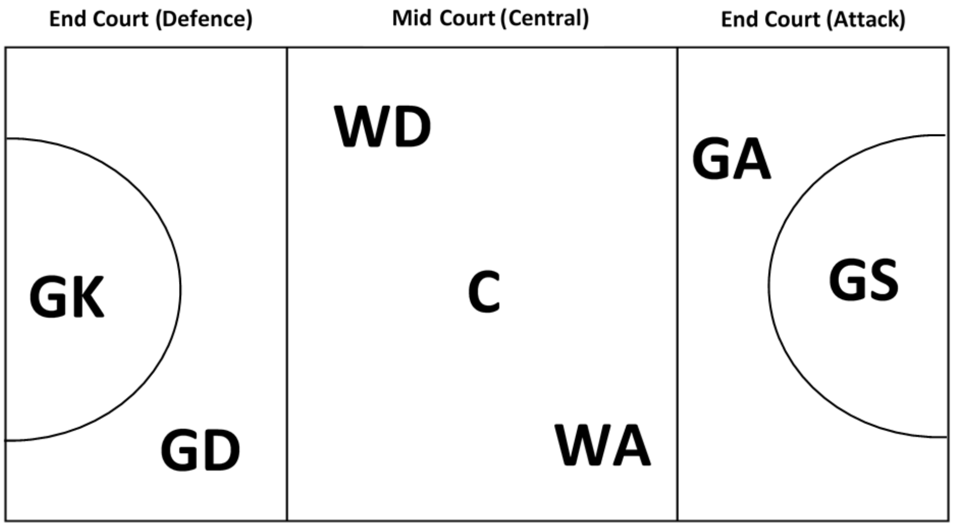

Figure 2.2: Representation of a netball court with player positions for a team attacking to the right. Positions: GK - Goal Keeper; GD – Goal Defence; WD – Wing Defence; C – Centre; WA - Wing Attack; GA – Goal Attack; GS - Goal Shooter

Netball is a court-based sport; therefore, the playing area is smaller than those of field-based sports. Despite this, the average distance covered per minute in court-based sports has been found to be similar to distances covered in field-based sports (Sweeting, Cormack, Morgan, Aughey & Edouard, 2017). The smaller space requires frequent changes of direction, often accompanied by high intensity movements to cover the opponent during defensive situations or to create space during attacking situations. Directional changes are common in netball, with up to 63.7 ± 7.6 changes of direction manoeuvres being implemented by a player in an international netball match (Fox *et al.*, 2013). It is not specified if the changes in direction were predetermined or as a response to external stimulus. However, the sheer number of directional changes in a match highlights the importance of this movement skill in netball.

Due to the spatial restrictions of each position, the distance covered as well as the occurrence of certain movements are mixed among positions. To closer inspect the game demands and activity patterns of each individual court position, Fox *et al.* (2013) analysed the Australian female netball team's video footage over the course of three international games. Instead of analysing individual players, the researchers studied footage of each court position. In the case of a substitution, data was collected of the player's replacement for the respective position. Player activity was categorised into five movement patterns: walking, jogging, shuffling, running and sprinting.

As expected, the frequency and the percentage of active time spent performing the movements varied between court positions. The average number of running actions executed in a game ranged from 26.7 ± 8.0 to 110.0 ± 12.5, accounting for 1.7 ± 0.4 to 6.7 ± 1.2 percent of the time spent active in a match. The frequency of sprinting actions in a match ranged from 4.7 ± 3.2 to 81.3 ± 20.1 across positions, while the percentage of active time spent doing the movement was 0.2 ± 0.1 to 4.8 ± 2.6. Running and sprinting actions were done most often by players in the mid-court (WD, C, WA), followed by attacking players (GA & GS) and lastly the defending players (GD & GK). Similar differences of movements executed were also found at a lower level of competition (Davidson & Trewartha, 2008). These findings highlight the fact that each position has a specific role to play in the game (i.e. scoring goals, defending goals or transitioning from defensive to attacking situations), thus the importance of each movement pattern varies among positions. Therefore, optimal training and recovery methods would also be position specific.

Constant changes of direction and the abrupt stop-start nature of netball regularly expose the players to considerable forces to the lower-limb joints. As a consequence of these characteristics of the sport, ankle and knee injuries have been reported to account for more than half of all the injuries sustained while playing netball (Ferreira & Spamer, 2010). Ferreira and Spamer noted that inadequate bio-motor abilities – agility, balance and explosiveness – or abnormal biomechanics of the players may serve as a contributing factor to netball players being susceptible to traumatic and overuse injuries.

While the position-specific physical demands of a netball match have been recorded, there is a lack of normative data for position-specific physical profiles among university level netball players. Due to the individualised physical demands typically required for a player in each positional area, the physical profile is most likely also not the same across positional areas. Having normative data for the position-specific physical profile of a netball player could assist coaches and practitioners to prescribe individualised training programmes to prepare players for the position-specific demands during match play.

A recent study (Thomas, Ismail, *et al.*, 2017) reported on the physical profiles of female youth academy netball players by position (age=15.51±1.49). In this study, the researchers recorded the height, body mass and certain performance-based tests for players in each positional category. The performance-based tests conducted in this investigation included jumping assessments (single leg hop test, squat jump test and countermovement jump test), SLS times (5m and 10m), CODS testing (505-CODS) and a cardio respiratory test (30-15 intermittent fitness test). Results indicated that the players categorised in the central positions (C, WA & WD) displayed significantly superior performances in all tests apart from one (single leg hop right leg), compared to defensive positions (GK &GD) and attacking positions (GS & GA). Players in defensive and attacking positions were shown to have significantly greater body mass in comparison to central players. Furthermore, defenders were found to be significantly taller compared to centres. No other significant differences were observed. While the findings of this study can be useful, it is important to note that the participants of this study were youth academy players (age=15.51±1.49). Physical capabilities develop in a non-linear manner because of physical growth and maturation, therefore it is recommended that similar research be conducted on players of different age groups and playing levels (Ferreira & Spamer, 2010; Thomas, Ismail, *et al.*, 2017).

In summary, netball is a fast-paced invasive team sport which entails a large amounts of direction changes and sudden decelerations. An effective and practical method of assessing CODS could assist practitioners to monitor and improve CODS ability of netball players.

Furthermore, due to specific positional court restrictions and duties it would appear that netball players of different positions would have varying physical characteristics and performances. On of the objectives of this study aims to add research to literature to help create position specific norm values for university level female netball athletes.

2.7. SUMMARY

CODS ability is regarded as a subfactor of agility. Prior to the detailed description of agility many tests developed to assess this bio-motor ability did not include a reactive element, thus the directional changes in the tests were pre-planned. It is currently understood that this type of tests assesses CODS ability. There are a variety of CODS tests commonly used among coaches of invasion team sport disciplines to assess CODS performance. The characteristics of the tests vary in terms of the amount of direction changes, the angle of direction change, the distance and the estimated time of completion. Performance in many of the commonly used CODS tests has been suggested to favour those with superior acceleration abilities. This has led to the investigation of new methods to assess CODS ability which gives a more isolated measure of the turning capability of an athlete running at high entrance levels.

The COD deficit is a proposed method of measuring CODS ability which removes the influence acceleration ability. It is calculated by subtracting the time of a SLS test from the total time a CODS test of equal overall distance took. The lower the deficit, the more effective an athlete is at changing direction relative to their sprinting capabilities. This is a relatively novel method of measuring CODS, thus literature regarding this method is scarce and limited to certain populations. The need to explore this method to confirm its validity is required.

Many previous studies have investigated the possible underlying factors of CODS performance. The correlation of acceleration ability and lower limb muscle qualities (e.g. strength, power, reactive strength) with CODS performances has often been investigated. The possible influence that postural control ability has on CODS is scarce among literature. The ability to effectively control the body’s centre of mass when changing direction at high velocities, could play a role in efficiently transitioning from deceleration to acceleration during a directional change.

CHAPTER THREE

METHODOLOGY

3.1. INTRODUCTION

This chapter gives an overview of the detailed research methods that were used to establish the aims and objectives of the current study. An explanation of the study design, the specific population that was recruited, the various testing protocols, as well as the statistical methods used to acquire the results are presented.

3.2. STUDY DESIGN

This research project was a field-based cross-sectional study designed to determine the relationship between selected bio-motor activities, namely change of direction speed, acceleration, and postural control.

3.3. PARTICIPANTS

The participants for the study were recruited from the Maties Netball Club of Stellenbosch University. A squad of 40 players was used, comprising of players from the first four teams. All the participants were club-level netball players and practiced on a regular basis (three times a week during the period of the research assessments). The netball players were informed that there was no obligation to be part of the study, and that participation was completely voluntary. Following the explanation of the study and the tests that will be performed, each participant was required to complete an informed consent form as well as a health screening form. The study took place during the latter part of the pre-season. It was not possible to blind the participants to the study; however, the aims and objectives of the study were not revealed.

Netball players were selected as the study sample because the results could be of importance to netball coaches and players. The rapid nature of the game requires frequent bursts and changes in direction while running at a high velocity, therefore change of direction speed (CODS) and acceleration are highly sought-after motor skills. The stop-start jumping and landing element of netball also necessitates adequate postural control skills. Understanding the relationships between these factors could assist coaches and players to enhancing these bio-motor skills through specific training programmes.

Players were included only if they were members of the Maties Netball Club and if they were participating in the 2017 pre-season training programme. Players were excluded if they had any injuries at the time of testing or within the six weeks prior to testing.

3.4. RESEARCH PROCEDURES

Initially, consent was given from the Chief Director of Maties sport, the manager of Maties netball and the coaching staff to approach the Maties netball squad. An information session about the study was given at the club general meeting prior to the beginning of the season. The players were informed of the study's protocol in writing and it was explained to them verbally. A written informed consent (Appendix A) was then completed by those willing to be a participant in the study. Players were asked if there were any short-term illnesses or conditions which would prevent a maximal effort. Recording sheets (Appendix B) were given to the players with their tag number on and they took the sheet to each testing station. The variables were measured in the following order: body composition, change of direction speed and finally acceleration. Postural control was done on a separate day with the players coming in arranged groups to be tested. All the postural control tests were done at the same time of day over three testing sessions. The sequence of testing was done as recommended by the Australian Sports Commission which is the order previously used by the Australian national netball squads (Ellis & Smith, 2000).

The researcher was assisted by three PhD students from the Department of Sport Science, who had experience in using the selected tests and were competent in the use of the equipment required to record the performance.

The performance tests were done in the Coetzenburg indoor sports hall and the motor learning laboratory, both of which are situated at Stellenbosch University's Department of Sport Science. The indoor sports hall has a non-slip surface on which competitive netball matches are played. Players were tested in their regular netball training gear, which was lightweight exercise clothing with shoes that were used for training and matches. All players were instructed to remove any support gear that was used while playing.

The data was collected over a single week during the pre-season training period during the middle of March 2017. Testing for acceleration and the change of direction speed were done on the same day for all the participants. Postural control was recorded during the rest of the week, prior to training for the day. Participants were divided into smaller manageable groups to test postural control.

3.5. ETHICS CONSIDERATIONS

The Departmental Ethics Committee (DESC) at Stellenbosch University and the Research Ethics Committee (REC) approved the study protocol of this project (Project number: SU-HSD-003784). The Maties Netball Club gave permission to use their netball equipment and premises to conduct the study. Informed consent forms were given to the participants who agreed to be part of the study. The protocol was thoroughly explained to the participants and any resulting questions were answered. It was made clear to the participants that taking part in the study was completely voluntary and that they could withdraw at any time during the study without penalty. Players were given participant numbers so that anonymity would be maintained when analysing the data. Data was kept safe on a personal password protected laptop. The data will be saved for up to five years after the study has taken place.

3.6. TESTS AND MEASUREMENTS

3.6.1. ANTHROPOMETRIC MEASUREMENTS

Body mass

The body mass of each player was determined using a self-calibrating digital scale (Seca, Germany) and recorded to the nearest 0.1 kilogram (kg). The participants were required to stand in the centre of the scale with their weight equally distributed on both legs whilst facing straight ahead.

Standing height

Standing height was measured while barefoot, using a portable stadiometer (Charder HM-200P Portstad, Charder Electronic Co Ltd, Taichung City, Taiwan). The head of the participant was placed in the Frankfurt plane with the feet together and the heels, buttocks and the upper back touching the stadiometer. The participants were requested to inhale deeply, followed by a relaxed and gentle exhale while maintaining an erect position. At the end of exhalation, the height was measured to the nearest 1cm. A registered biokineticist with ISAK Level I qualification performed the anthropometric measurements.

3.6.2. PERFORMANCE TESTING

Prior to the performance testing, participants did a standardised five-minute warm-up which was given by a Biokinetic Honours student. The warm-up consisted of jogging, various dynamic stretches and two sprints from stationary starts over a distance of 25 meters.

The 505-CODS test

The 505-CODS test is a commonly used change of direction agility test in various team sports, which includes netball (Barber *et al.*, 2015). A layout of the test is shown in figure 3.1. The official starting point of the 505-CODS test was set up with one pair of timing gates with the zero line five meters away from the timing gates. Players could start the test at a run up point which was ten meters away from the official starting line of the test. The participants were instructed to start their run up for the test whenever they were ready.

Recording of the test started as soon as the participants passed the timing gates after the ten-meter run up. Once the zero line was reached they had to turn and accelerate back past the official starting point which ended the recording of the test. Participants were instructed to do three trials turning on their right foot and then three trials turning on their left foot. The times from each trial was recorded to the nearest 0.01 seconds. The 505-CODS test was found to have a validity of 0.90 (r=0.90) with a typical error of measurement 1.9% (TE=1.9%) (Gabbett *et al.*, 2008). The players were required to indicate whether they are right or left dominant.

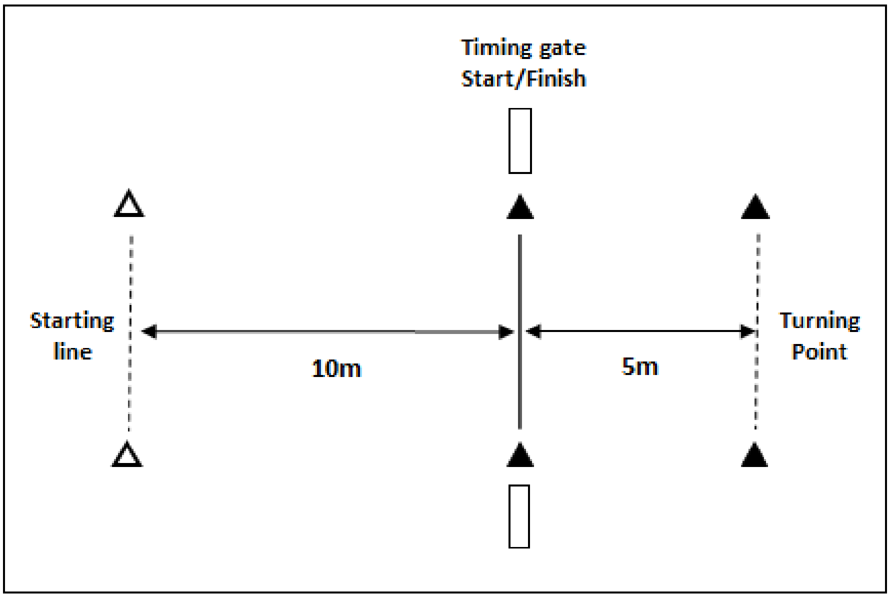

Figure 3.1: The 505-CODS test setup

20m Sprint

The 20m sprint test is a common test done in a variety of team sports which ultimately tests an athlete's acceleration ability. Due to the restricted space on the court, acceleration ability is very relevant information to use as a performance measure in netball players. Figure 3.2 illustrates how the 20m sprint was set up. The width of the runway for the sprint test was 2m and the starting line was marked with tape and cones. Photocells (Brower Timing Systems speed gates, Salt Lake City, UT, USA) were set up at the starting point as well as 5m, 10m and 20m from the starting point. The Brower timing system has been shown to be a valid and reliable tool to measure acceleration (Shalfawi, Enoksen, Tonnessen & Ingebrigsten, 2012). Photocells were placed perpendicular to each other and the recorded times to the nearest 0.01s at each of the mentioned recording points. The height of the photocells was set at around waist height of the participants so that the displacement of the centre of mass was measured.

Participants were instructed to start all the sprint trials in a readied stance position with both feet behind the starting line. After a signal was given that the timing gates were set and ready, the participants could start whenever they wished. The participants were required to run through the runway as fast as possible. To prevent deceleration prior to the end, two cones were placed 5m beyond the finish line and the participants were instructed to sprint up until that point. Three sprint trials were done, with a two-minute rest period between each maximal sprint effort. This sprint test has been shown to produce accurate repeatable results without requiring familiarization to the test (Moir, Button, Glaister & Stone, 2004). It has been reported that the 10m sprint showed to have a coefficient of variance (CV) of 2.0% and an intraclass correlation coefficient (ICC) of 0.93, while the 20m sprint was shown to have a CV of 1.0% and an ICC of 0.91. The fastest time over the three trials was analysed further.

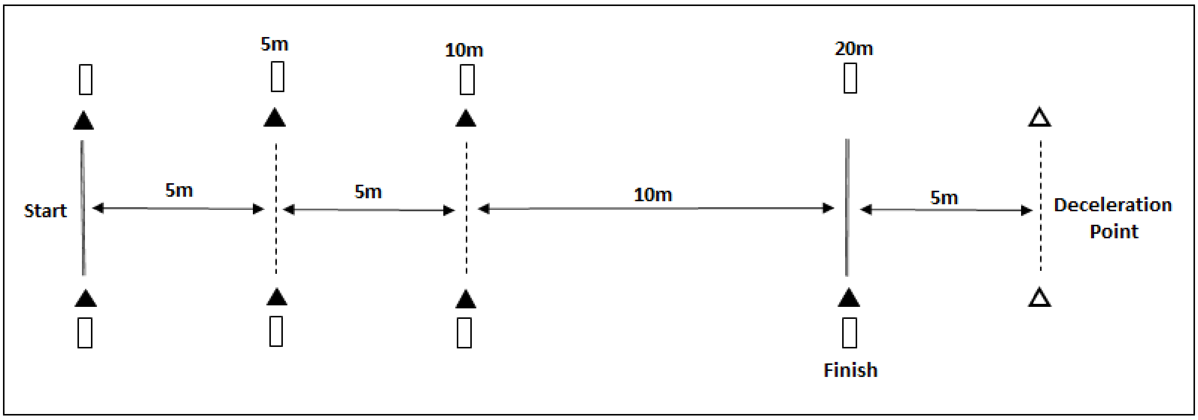

Figure 3.2: The 20m straight-line sprint setup

Spatiotemporal gait parameters

Spatiotemporal gait paramaters were recorded using the OptoGait photoelectric cell system (Microgate S.r.I, Bolzano, Italy). The optical sensors worked at a frequency of 1000Hz with an accuracy of 1cm. The parameters measured were stride length (m), stride frequency (stride/s), flight time (s) and ground contact time (s). Figure 3.3 shows data capturing with the OptoGait system during a straight-line sprint test.

The OptoGait system has been deemed a reliable and valid means of assessing the above-mentioned gait parameters (Lee, Song, Lee, Jung, Shin & Shin, 2014). Lee *et al.* (2014) found high retest reliability scores for stride frequency, stride length, ground contact time and flight time (ICC=0.929-0.988). The SEM between two sessions was found to be for all parameters (2.17-5.96%), thus indicating strong and absolute reliability. In the same study, the coefficients of variation of method error (CV_{ME}) was calculated between the OptoGait and Gaitrite electronic walkway (CIR System Inc., Clifton, NJ, USA). The CV_{ME} values were found to be low for stride frequency and stride length (0.32% and 1.37% respectively) and slightly higher, but still low, for ground contact time and flight time (3.37% and 4.07% respectively).

Figure 3.3: A participant completing a 20m straight-line sprint with the spatiotemporal gait parameters being measured via the OptoGait (Photograph by Jaiyesimi, B.G.)

Postural Control

Postural control was measured by using an instrumented test of postural sway (ISway). The ISway system uses a body-worn sensor to measure the amount of sway present during bipedal and unipedal stance. The sensor was mounted to the posterior trunk in line with the 5th lumbar vertebrae which is near the body centre of mass. The sensors contained 3-D accelerometers which wirelessly recorded 3-D linear accelerations and angular velocity which is reported as Jerk. Jerk is defined as the sway jerkiness, time derivative of acceleration (Mancini *et al.*, 2012). The data is continuously streamed to a laptop via a Bluetooth connection from the sensor where it is stored to a custom MATLAB interface to analyse the different components of postural control.

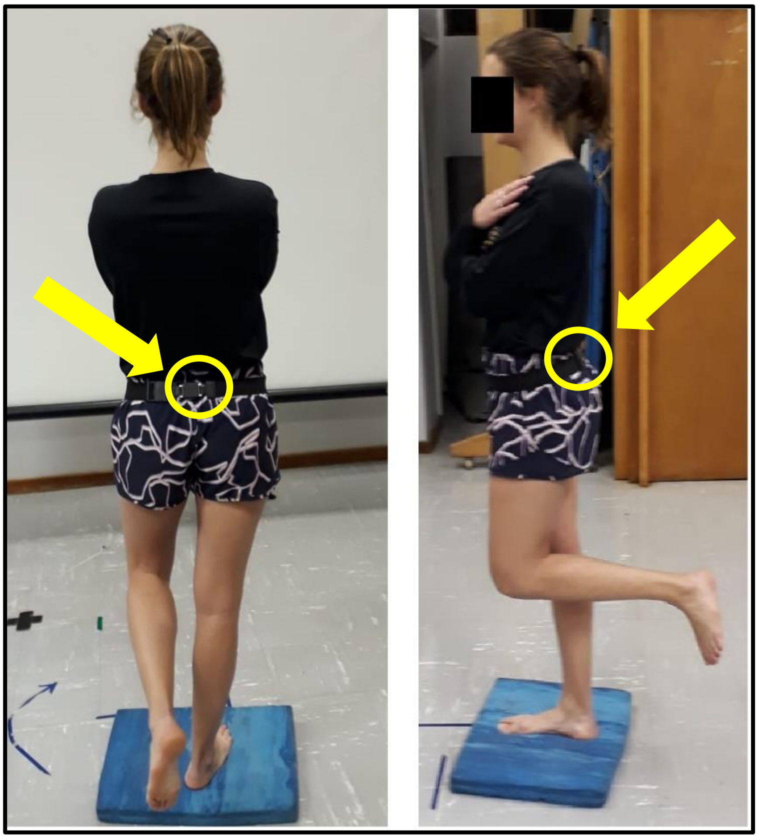

Figure 3.4: A participant being assessed for postural control on a foam surface using the ISway system (Photograph by Lombaard, J.)

Players were tested barefoot according to the required protocol of the ISway assessments. The protocol used was the modified clinical test for sensory interaction on balance (mCTSIB) Different testing procedures were followed to isolate specific balance systems for analysis. The testing procedures were as follows: 1) open eyes on a firm surface; 2) closed eyes on a firm surface; 3) eyes open on a foam surface; 4) eyes closed on a foam surface. Each procedure described was done in a unipedal stance with the dominant leg followed by a unipedal stance on with the non-dominant leg. To obtain a high score in postural control, the amount of postural sway (or Jerk) had to be as low as possible for each testing procedure. During the procedures where unipedal stance was done, each time a participant required the non-balancing leg to maintain balance it as recorded by the researcher. The ISway system was found to be a reliable and valid tool to measure postural control in a study by Mancini *et al.* (2012). Mancini *et al.* (2012) compared the degree of postural sway recorded using the ISway system to the degree of postural sway recorded using a force plate in healthy subjects as well as subjects who had Parkinson's disease. Appendix C displays an example of the report which was given to the netball players.

3.7. STATISTICAL ANALYSIS

Statistica (13.2.92.1 64-bit) was used to do all of the statistical analysis. Descriptive statistics of the players' physical characteristics and scores of the tests are reported as mean and standard deviations. Correlation analyses to test for relationships between measurements were done using Spearman correlations. Body measurements were compared between position groups using a one-way ANOVA. In all cases where within subjects' measurements were tested (e.g. comparing dominant vs non-dominant, eyes open/closed etc), mixed model ANOVA's were done with the subjects as random effect. Fisher least significant difference (LSD) was used for post hoc comparisons.

The scale of the strength of reported correlations throughout this study was evaluated as follows: trivial (0.0 – 0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99) (Hopkins, 2000).

CHAPTER FOUR

RESULTS

4.1. INTRODUCTION

The primary aim of this study was to determine the relationship between change of direction speed, acceleration and postural control among university level female netball players. The secondary aim was to determine the relationship between sprinting spatiotemporal gait variables, acceleration and change of direction speed among university level female netball players. Each investigated hypothesis is stated in the appropriate results section.

4.2. PARTICIPANT CHARACTERISTICS

Table 4.1 displays the physical characteristics of all the netball players and their performances in the bio-motor tests. The mean, standard deviation (SD) and the 95% confidence interval (CI) are shown for each variable.

Table 4. 1. Physical characteristics and performance test results of all participants (data are represented as mean ± SD)

Characteristics	**Total (n=38)**		
	Mean	SD	95% CI
Age (years)	19.50	±1.22	19.10 - 19.90
Height (cm)	173.87	±5.97	171.91 - 175.84
Weight (kg)	69.27	±7.55	66.79 - 71.75
505 D (s)	2.55	±0.10	2.51 - 2.58
505 ND (s)	2.59	±0.11	2.56 - 2.63
COD deficit D	0.62	±0.12	0.58 - 0.65
COD deficit ND	0.67	±0.12	0.63 - 0.70
5m sprint (s)	1.10	±0.09	1.07 - 0.12
10m sprint (s)	1.93	±0.12	1.89 - 1.97
20m sprint (s)	3.42	±0.19	3.36 - 3.48
Key: 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant limb			

4.3. CODS PERFORMANCE CORRELATIONS

Hypothesis one: *The two methods of assessing change of direction speed (505-CODS test and the COD deficit) would reveal a significant positive inter-relationship with one another, while change of direction speed evaluated as the total time of the 505-CODS test would reveal a significant positive inter-relationship with acceleration, whereas change of direction speed evaluated via the COD deficit would not reveal a significant positive inter-relationship with acceleration.*

Hypothesis two: *There will be no significant inter-relationship between change of direction speed and the single leg postural control scores.*

The correlation data with 95% CI is presented for 505-CODS performance in Table 4.3. The dominant and non-dominant sides were examined separately. Moderate significant positive associations between 505-CODS time and the COD deficit were observed for both D and ND CODS performance (r=0.41-0.49; p<0.01).

Table 4. 2. Spearman correlation between mean 505-CODS test time, 5m, 10m and 20m sprint time and unipedal static postural control scores according to the four conditions of the mCTSIB protocol.

505-CODS test				
Tests	D		ND	
	r	p	r	p
COD deficit (s)	0.41**	<0.01	0.49**	<0.01
5m sprint (s)	0.48**	<0.01	0.37*	0.02
10m sprint (s)	0.46**	<0.01	0.42**	<0.01
20m sprint (s)	0.56**	<0.01	0.54**	<0.01
Opened eyes – Firm surface	-0.17	0.32	0.25	0.14
Closed eyes – Firm surface	0.08	0.63	0.22	0.19
Opened eyes – Foam surface	0.12	0.32	0.19	0.26
Closed eyes – Foam surface	-0.12	0.56	0.19	0.26

Key: 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant leg
* Denotes significance at p≤0.05
** Denotes significance at p≤0.01

Moderate significant positive correlations were demonstrated between 505-CODS times and SLS times over the 5m mark (r=0.37-0.48; p<0.05) and the 10m mark (r=0.42-0.46; p<0.01). A large significant positive relationship was found for 505-CODS test time and the 20m SLS time (r=0.54-0.56; p<0.01).

No significant correlations were found between the 505-CODS times and the single leg postural control (PC) scores. Small non-significant correlations were found between the 505-CODS time and PC condition 1 (open eyes – firm surface) for the dominant (r=-0.17; p=0.32) and non-dominant leg (r=0.25; p=0.14). For PC condition 2 (closed eyes – firm surface) had a trivial non-significant correlation with the 505-CODS test for the dominant leg (r=0.08; p=0.63) and a small non-significant correlation for the non-dominant leg (r=0.22; p=0.19) was noted. Small non-significant correlations were found between the 505-CODS time and PC condition 3 (open eyes – foam surface) for the dominant (r=0.12; p=0.32) and non-dominant leg (r=0.19; p=0.26). Lastly, small non-significant correlations were found between the 505-CODS time and PC condition 4 (closed eyes – foam surface) for the dominant (r=-0.12; p=0.56) and non-dominant leg (r=0.19; p=0.26).

Table 4. 3. Spearman correlation between mean COD deficit, 5m, 10m and 20m sprint time and unipedal static postural control scores according to the four conditions of the mCTSIB protocol

COD Deficit				
Tests	D		ND	
	r	p	r	p
505-CODS (s)	0.41**	<0.01	0.49*	<0.01
5m sprint (s)	-0.47**	<0.01	-0.53*	<0.01
10m sprint (s)	-0.53**	<0.01	-0.54**	<0.01
20m sprint (s)	-0.36**	0.03	-0.32*	0.05
Opened eyes – Firm surface	0.01	0.95	0.23	0.18
Closed eyes – Firm surface	0.01	0.93	0.05	0.77
Opened eyes – Foam surface	0.15	0.40	0.30	0.07
Closed eyes – Foam surface	-0.11	0.51	-0.01	0.94

Key: 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant leg
* Denotes significance at p≤0.05
** Denotes significance at p≤0.01

The correlation data with 95% CI for the COD deficit performance is shown in Table 4.3. The dominant and non-dominant sides were examined separately. This table reveals that COD deficit had a significant inverse relationship with acceleration performances.

The 5m SLS time was shown to have a moderate inverse relationship with the COD deficit of the dominant leg performance ($r=-0.47$; $p<0.01$) and a strong inverse relationship with the non-dominant leg performance ($r=-0.53$; $p<0.01$). A strong inverse correlation was found between 10m SLS times and the COD deficit for turning with the dominant and non-dominant side ($r=-0.53$; $p<0.01$) and for turning on the non-dominant side ($r=0.54$; <0.01). For the 20m SLS times, a moderate inverse correlation was found for the COD deficit for the dominant side ($r=-0.36$; $p<0.01$) and the non-dominant side ($r=-0.32$; $p<0.05$). No significant relationship was demonstrated between the COD deficit performances and the PC performances. PC condition 1 had a trivial non-significant correlation with the COD deficit for the dominant leg ($r=0.01$; $p=0.95$) and a small non-significant correlation for the non-dominant leg ($r=0.23$; $p=0.18$). Trivial non-significant relationship was found for the COD deficit and PC condition 2 for the dominant ($r=0.01$; $p=0.93$) and non-dominant leg ($r=0.05$; $p=0.77$). The PC condition 3 had a small non-significant relationship with the COD deficit for the dominant leg ($r=0.15$; $p=0.40$) and a moderate non-significant relationship for the non-dominant leg ($r=0.30$; $p=0.07$). Lastly, for PC condition 4 and the COD deficit there was a small non-significant correlation for the dominant leg ($r=-0.11$; $p=0.51$) and a trivial non-significant correlation for the non-dominant leg ($r=-0.01$; $p=0.94$).

4.4. CODS ASYMMETRIES

Hypothesis three: *The asymmetries between legs for change of direction speed ability would be significantly larger when using the COD deficit compared to using the total time of the 505-CODS test.*

Table 4.4. displays the mean CODS performances of the university netball players, along with the mean imbalance percentage between performances of respectively the dominant and non-dominant legs. The mean, standard deviation (SD) and the 95% confidence interval (CI) are also shown in the table.

Table 4. 4. The dominant versus non-dominant comparisons for the 505-CODS test time and the COD deficit with the between leg imbalance percentage.

	D			ND			Imbalance (%)	
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD
505-CODS (s)	2.55*†	± 0.10	2.51-2.58	2.59†	0.11	2.56-2.63	-3.20†	±2.45
COD deficit (s)	0.62*	± 0.12	0.58-0.65	0.67	0.12	0.63-0.70	-14.42	±11.68

Key: 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant leg; Imbalance % = the percentage difference between dominant and non-dominant performances
*significantly different to non-dominant leg (p≤0.05)
†significantly different to the COD deficit

CODS performances were significantly faster when turning with the dominant leg, compared to turning with the non-dominant leg (p≤0.05). The imbalance percentages calculated for CODS performances was significantly higher when CODS was expressed as the COD deficit compared to the 505-CODS test time (p≤0.05).

4.5. POSITION-SPECIFIC CHARACTERISTICS

Hypothesis four: *There would be a significant difference in certain physical characteristics of netball players from different positional areas.*

The mean ± SD values for the physical characteristics such as age, height and body mass of female university netball players by position can be found in Table 4.5. The performances in the 20m SLS (split at 5m, 10m and 20m) and CODS (505-CODS test and the COD deficit) are also displayed in Table 4.5.

Post-hoc analysis revealed that mid-court players were significantly shorter compared to the attacking players (p=0.02) and the defensive players (p=0.01). Body mass was significantly different with the attackers found to be significantly heavier than the mid-court players (p=0.02).

Table 4. 5. Physical characteristics and performance test results of university netball players by position (data are represented as mean ± SD).

Characteristics	Attackers (n=12)			Mid-court (n=15)			Defenders (n=11)		
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
Height (cm)	175.87	±6.29	171.87 - 179.86	170.49 [a b]	±5.65	167.36 - 173.61	176.32	±3.93	173.68 - 178.96
Weight (kg)	72.58	±8.60	67.11 - 78.04	65.95 [a]	±6.64	62.28 - 69.63	70.18	±6.13	66.06 - 74.30
5m sprint (s)	1.14	±0.07	1.10 - 1.19	1.07 [a]	±0.08	1.02 - 1.12	1.08	±0.09	1.02 - 1.14
10m sprint (s)	2.00	±0.09	1.94 - 2.06	1.89 [a]	±0.11	1.83 - 1.95	1.90 [a]	±0.11	1.83 - 1.98
20m sprint (s)	3.56	±0.16	3.46 - 3.66	3.33 [a]	±0.17	3.23 - 3.42	3.40 [a]	±0.18	3.28 - 3.52
505-CODS D (s)	2.56	±0.11	2.50 – 2.63	2.54	±0.11	2.49 – 2.60	2.53	±0.10	2.47 – 2.60
505-CODS ND (s)	2.62	±0.11	2.55 – 2.68	2.56	±0.12	2.51 – 2.62	2.61	±0.08	2.55 – 2.68
COD deficit D (s)	0.56	±0.11	0.49 - 0.63	0.66	±0.11	0.61 - 0.74	0.63	±0.11	0.55 - 0.73
COD deficit ND (s)	0.62	±0.10	0.55 - 0.68	0.68	±0.13	0.59 - 0.73	0.71	±0.11	0.63 - 0.76

Key: 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant leg; CI = confidence interval

[a] significantly different from attackers

[b] significantly different from defenders

In the 5m SLS performances, the attackers were significantly slower than the mid-court players (p=0.02). 10m SLS performances were significantly slower in attacking players than the mid-court players (p=0.01) and the defending players (p=0.04). For the 20m SLS, a significant difference in performance was observed for attacking players and mid-court players (p=0.001). The results show the attacking players were also significantly slower than the defending players (p=0.03). No other significant differences between groups were found. Regarding the 505-CODS times, no significant difference was found between attackers and mid-court players (p=0.34), attackers and defensive players (p=0.66) or for mid-court players and defensive players (p=0.64). For the COD deficit, there was no significant difference between attacking players and defenders (p=0.07), attacking players and defenders (p=0.08) or between mid-court players and defenders (p=0.95).

4.6. POSTURAL CONTROL ANALYSIS

Hypothesis five: *The netball players would display the most amount of postural sway during condition 4 (eyes closed and on the foam surface) of the mCTSIB protocol.*

Figure 4.1. indicates that the netball players had significantly more postural sway when tested with closed eyes on the foam surface than all three of the other testing conditions ($p<0.05$). There was no significant difference between the three other testing conditions.

For opened eyes on the firm surface compared to eyes closed on a firm surface, the results displayed a medium Cohen's D value ($d=0.50$). Opened eyes on the firm surface had a medium difference to opened eyes on the foam surface ($d=0.45$). Opened eyes on the firm surface had a huge difference with closed eyes on the foam surface ($d=1.71$). The postural control differences between sides were found to be negligible.

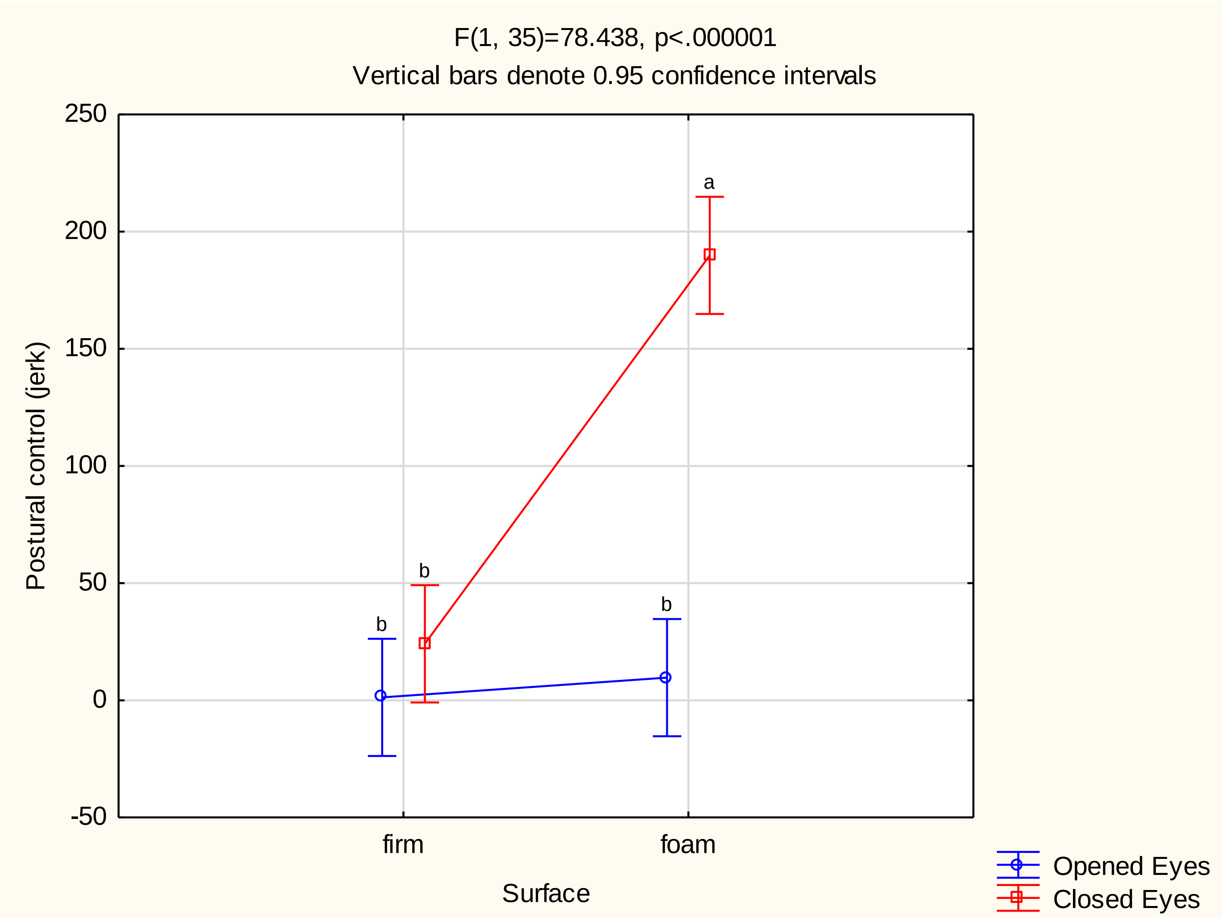

Figure 4.1. The amount of Jerk during the modified Clinical Test for Sensory Interaction on Balance (mCTSIB) protocol.

4.7. SPRINT SPATIOTEMPORAL VARIABLES CORRELATIONS

Hypothesis six: *The spatiotemporal variables measured during the straight-line sprints would be significantly correlated to acceleration and change of direction speed measured as the 505-CODS test time, whereas no significant correlation would be found between the spatiotemporal variables and the COD deficit.*

In Table 4.6. the correlation data with 95% CI is shown for the sprinting spatiotemporal variables. The ground contact time (GCT) was found to have a positive significant relationship with SLS performances of a moderate correlation at the 5m mark (r=0.38; p=0.02), and large correlations at the 10m mark (r=0.51; p<0.01) and the 20m mark (r=0.60; p<0.01). The stride frequency (SF) was shown to have a moderate significant inverse relationship only at the 20m point (r=-0.42; p=0.01). Whereas a small non-significant inverse correlation was found at the 5m (r=-0.26; p=0.13) and the 10m mark (r=-0.24; p=0.16). No significant correlation was shown between the stride length (SL) and SLS performances at the 5m (r=-0.04; p=0.81), 10m (r=-0.18; p=29) and 20m (r=-0.06; p=0.72) split times. Similarly, no significant correlation was found between the flight time (FT) and the SLS times at the 5m (r=0.02; p=0.90), 10m (r=-0.15; p=0.37) and 20m (r=-0.01; p=0.97) split times.

Table 4. 6. Spearman correlation between mean spatiotemporal gait variables and the 5m sprint time, 10m sprint time, 20m sprint time, the 505-CODS test time and the COD deficit.

Tests	SF (step/s)		SL (cm)		FT (s)		GCT (s)	
	r	p	r	p	r	p	r	p
5m sprint (s)	-0.26	0.13	-0.04	0.81	0.02	0.90	0.38*	0.02
10m sprint (s)	-0.24	0.16	-0.18	0.29	-0.15	0.37	0.51**	<0.01
20m sprint (s)	-0.42**	0.01	-0.06	0.72	-0.01	0.97	0.60**	<0.01
505-CODS D (s)	-0.41**	0.01	0.03	0.84	0.19	0.25	0.42**	0.01
505-CODS ND (s)	-0.36*	0.03	0.10	0.56	0.19	0.27	0.31	0.07
COD deficit D (s)	-0.06	0.73	0.15	0.39	0.22	0.21	-0.10	0.57
COD deficit ND (s)	-0.07	0.67	0.18	0.28	0.25	0.14	-0.16	0.34
Key: SF = stride frequency; SL = stride length; FT = flight time; GCT = ground contact time; 505-CODS = 505 change of direction speed test; COD deficit = change of direction deficit; D = dominant limb; ND = non-dominant leg								

The 505-CODS performances were shown to have a moderate significant inverse correlation with SF when turning with both the dominant (r=-0.41; p=0.01) and non-dominant limb (r=-0.36; p=0.03). A moderate significant positive correlation was found for 505-CODS total time for the dominant limb and GCT (r=0.42; p=0.01). A moderate non-significant relationship was found for the non-dominant limb and GCT (r=0.31; p=0.07). No significant correlations were found between SL and the 505-CODS test for the dominant (r=0.03; p=0.84) or the non-dominant leg (r=0.10; p=0.56). No significant relationship was found between FT and the 505-CODS test time for the dominant (r=0.19; p=0.27) and the non-dominant leg (r=0.19; p=0.21).

Regarding the relationship between the spatiotemporal gait variables and the COD deficit performances, no significant correlations were found. A trivial non-significant relationship was found between SF and the COD deficit performance for the dominant (r=-0.06; p=0.73) or non-dominant leg (r=-0.07; p=0.67). A small non-significant correlation was found between SL and the COD deficit performance for the dominant (r=0.15; p=0.39) or non-dominant leg (r=0.18; p=0.28). A small non-significant correlation was found between FT and the COD deficit performance for the dominant (r=0.22; p=0.21) or non-dominant leg (r=0.25; p=0.14). Lastly, a small non-significant correlation was found between GCT and the COD deficit performance for the dominant (r=-0.10; p=0.57) or non-dominant leg (r=-0.16; p=0.34).

CHAPTER FIVE

DISCUSSION

INTRODUCTION

The primary aim of this study was to determine the relationship between change of direction speed, acceleration and postural control among university level female netball players. The secondary aim was to determine the relationship between sprinting spatiotemporal gait variables, acceleration and CODS among university level female netball players.

MAIN FINDINGS

The discussion section is structured in accordance with the hypotheses and the objectives of the current study, which were introduced in chapter one. Following the hypotheses, it is stated whether the hypotheses were accepted or rejected.

HYPOTHESIS ONE

The two methods of assessing change of direction speed (505-CODS test and the COD deficit) would reveal a significant positive inter-relationship with one another, while change of direction speed evaluated as the total time of the 505-CODS test would reveal a significant positive inter-relationship with acceleration, whereas change of direction speed evaluated via the COD deficit would not reveal a significant positive inter-relationship with acceleration – **HYPOTHESIS ACCEPTED.**

The objective stated was to determine the inter-relationships between change of direction speed (505-CODS time), COD deficit and acceleration ability.

The 505-CODS test versus the change of direction deficit

Results of the current study showed a moderate positive association between the 505-CODS time and the COD deficit for both dominant and non-dominant leg CODS performance. Cuthbert *et al*. (2017) reported a moderate correlation when pivoting with the right leg, while pivoting with the left leg revealed a slightly stronger relationship between the two variables. The participants in the study by Cuthbert *et al.* (2017) were 36 male team sports athletes, consisting of 23 rugby union and 13 soccer players. It must be noted that, unlike the current study, Cuthbert *et al.* (2017) did not sort the planted leg in accordance to the participants' preferred side (i.e. dominant and non-dominant). Instead, the pivoting legs were only sorted as left and right.

Among female youth academy netball players, Dos'Santos *et al.* (2018) found a large significant positive correlation when cutting with the limb classified as the dominant side, as well as cutting with the non-dominant side in female netball players. It must be taken into consideration that the classification of limb dominance in the study by Dos'Santos was done according to the stepping leg that had fastest 505-CODS total time.

In a study using 17 male cricket players, Nimphius *et al.* (2016) found very strong significant correlations for the preferred turning side and for the non-preferred side. Methodological differences between the current study and the study by Nimphius *et al*. (2016) could possibly explain the varying strength of the relationships. As seen with the investigation by Dos'Santos et al. (2018), the preferred side was classified as the turning leg with the fastest time, while the other side was referred to as the non-preferred side. Another methodological difference which was noted in the study by Nimphius *et al*. (2016) was the period within the season when the testing took place. Testing for the study was done in the middle of the competitive season, whereas testing was done during the pre-season in the current study.

Sporting background of the participants used in the various studies could have an influence on performance of the CODS test. The nature of the directional change executed in the CODS test could be more familiar to participants from certain sports. For example, the 180° turn in the 505-CODS test closely mimics the action of a cricket batsman when running between wickets. This could possibly affect the performances in these specific tests, thus also affecting the strength of relationships.

The 505-CODS test versus acceleration ability

In the current study, the 505-CODS test was found to have a moderate correlation to acceleration over all the straight-line sprint (SLS) distances. The finding that CODS ability measured as the total time is significantly correlated to acceleration ability, is similar to several studies which used the same CODS test. Although most studies investigated show a significant relationship between these two bio-motor abilities, the strength of the relationship is varied. Across literature, acceleration ability was assessed over distances ranging from 5m to 30m. For the relevance of the current study, the findings of studies which used 5m, 10m and 20m SLS times will be mentioned.

Four studies were found which reported a significant correlation between 5m SLS time and the 505-CODS test (Cuthbert *et al.*, 2017; Gabbett *et al.*, 2008; Jones *et al.*, 2009; Sayers, 2015). Results from Cuthbert *et al.* (2017) have the closest resemblance to the findings of the current study. Investigators reported a moderate correlation (r=0.42) between the 5m SLS time and the 505-CODS turning with the left leg. Cutting with the right leg revealed a stronger relationship with the SLS time (r=0.57). As previously mentioned, Cuthbert *et al.* (2017) did not classify the legs used to change direction according to a preferred or dominant side.

Similarly, Jones *et al.* (2009) reported a moderate significant correlation (r=0.518) among a group of university students from various sporting backgrounds. The study population consisted of male and female participants, however, around 87% of the participants were male. Gender specific relationships were not calculated. The strength of this correlation was similar to that found among Australian rugby league players in a study by Gabbett *et al.* (2008), who also reported a moderate relationship between the two test times (r=0.52). Sayers *et al.* (2015) reported the strongest relationship between 505-CODS performance and 5m SLS performance (r=0.89). It should be noted Sayers *et al.* (2015) had only 15 participants in their study, which could have influenced the results.

The 10m SLS time was the most commonly used distance to determine acceleration ability in the literature found. As with the 5m SLS time, Cuthbert *et al.* (2017) had similar findings to the current study. The turn with the right leg revealed a significant moderate relationship (r=0.49) with the 505-CODS test. Turning with the left leg was shown to have a large correlation (r=0.54).

Nimphius *et al.* (2010) calculated the correlation between acceleration and CODS at three different periods within a competitive softball season (pre-season, mid-season and post-season). The strength of the correlation differed when turning with the dominant and non-dominant limb, while the correlation also varied at the different periods of performance assessment. During the pre-season period, only turning with the non-dominant limb was significantly correlated to the 10m SLS time (r=0.76). The assessments by Nimphius *et al.* (2010) during the middle of the season revealed a significant correlation when turning on the dominant limb (r=0.81) and the non-dominant limb (r=0.76). Lastly, the post-season testing results revealed a near perfect correlation only for the non-dominant limb (r=0.96), while the dominant side was not significantly correlated for the 10m SLS performance. These results demonstrate how cross-sectional relationships may fluctuate throughout a season. Thus, the physical conditioning of the athletes could influence the strength of the relationships found among studies.

Dos'Santos *et al.* (2018) was the only study found which did not report a significant correlation but a trend (r=0.355; p=0.058; r=0.359; p=0.054) between 505-CODS test and 10m SLS performance. A possible reason for the different findings could be due to the methodological differences between the current study and Dos'Santos *et al.* (2018). While many similarities existed (e.g. sample size, population, tests used) between the current study and the study by Dos'Santos (2018), the method of classifying a participant's dominant and non-dominant limb was different. In the study by Dos'Santos *et al.* (2018) the plant foot with the fastest 505-CODS test completion time was defined as the dominant side, while the other leg was classified as the non-dominant side. In the current study the dominant side was based on limb preference, therefore it is not necessarily the turning limb equating to a superior performance.

All the correlations mentioned in the studies above, as well as the current study, would indicate that performance in the 505-CODS test favours those athletes with superior acceleration. It could therefore mean that the 505-CODS test is not the best test to determine true COD ability, because acceleration ability plays such a significant role in the performance of the test as the total time.

The COD deficit versus acceleration ability

The finding that the COD deficit has a significant negative relationship with acceleration performance among female netball players is similar to the results from Dos'Santos *et al.* (2017). The investigators also reported significant inverse correlations between the CODD performances and the time recorded at the 10m mark during a SLS. The results revealed that the COD deficit had a strong inverse correlation with the acceleration performance when turning with either the dominant (r=-0.66) or non-dominant leg (r=-0.539). This result suggests that the slower netball players had a lower COD deficit than the faster players. Dos'Santos *et al.* (2018) suggested that an inverse correlation demonstrates that the youth netball players may have had a deficient eccentric strength capacity, which is fundamental for efficient deceleration during a 180° directional change.

In contrast, Nimphius *et al.* (2016) reported no significant correlations between the COD deficit and SLS performances. As with the current study, Nimphius *et al.* (2016) also calculated the COD deficit by subtracting the time of the 10m SLS from the time taken to complete the 505-CODS test. The investigators concluded that the lack of a significant correlation between the COD deficit and the SLS times meant that this method of assessing CODS eliminated the masking influence that acceleration ability is suggested to have when using the total time of a CODS test such as the 505-CODS test. Cuthbert *et al.* (2017) also found no significant difference between SLS performances and COD deficit for directional changes with the left leg. However, directional changes with the right leg was shown to have a moderate inverse correlation with 10m SLS time (r=-0.38). Despite this result, the investigators suggest that the lack of a significant relationship in the left leg showed that the COD deficit is not influenced by sprinting ability. However, the inverse relationship does show that COD deficit is a more isolated measure of COD ability.

It is possible that these correlation differences may be influenced by the sex of the participants used in the studies. The inverse correlations were found in the current study and Dos'Santos *et al.* (2018), both testing netball players. The sex differences in COD deficit is a topic that could possibly be further investigated.

HYPOTHESIS TWO

There will be no significant inter-relationship between change of direction speed and the single leg postural control scores – **HYPOTHESIS ACCEPTED.**

The objective stated was to determine the inter-relationship between change of direction speed and postural control ability.

Limited research has been done which investigates if CODS ability is influenced by postural control (PC). No research was found which used the ISway system to evaluate PC under the modified clinical test for sensory interaction on balance (mCTSIB) protocol among a sporting population. Therefore, comparisons to previous research are limited to studies which used other methods of assessing PC.

The investigation done by Sekulic *et al.* (2013) was the only study found which assessed PC in a static manner. Sekulic *et al.* (2013) used the Biodex Balance system to assess the correlation between control of posture and performances in a set of pre-planned CODS tests. Two separate tests were conducted on the biodex balance system to determine the participant's overall stability index (OSI) and limit of stability (LOS). The correlations for male and female participants were calculated separately. The results of female participants revealed no significant correlation was found for the OSI score and four of the five different CODS tests used. The 20Y (or pro-agility) test was the only CODS test found to be significantly correlated (r=0.37) to the OSI score. Regarding the LOS scores, no significant correlation was found between the LOS and any of the CODS tests among the female participants.

Among the male participants in the study by Sekulic *et al.* (2013), PC performances seem to have a greater influence on CODS performance. The results reveal a significant relationship between OSI scores and CODS performances in three of the five CODS tests used. The OSI scores were shown to have a moderate positive correlation with performances in the zigzag test (r=0.40) and the FWDBWD test (r=0.37), while the T-test displayed a strong correlation (r=0.58). Furthermore, two of the five CODS tests were found to be significantly correlated to LOS scores. The performances in the zigzag test and the T-test were shown to have a moderate inverse relationship with LOS (r=-0.44 and r=-0.47 respectively).

Despite the methodological differences between the current study and the study by Sekulic *et al.* (2013), these findings demonstrate that the strength of the relationship between CODS performance and PC could be influenced by sex. The investigators conclude that the results indicate that PC should be considered as a potential predictor of CODS in trained adult males, but not among trained adult females. This conclusion from Sekulic *et al.* (2013) seems to agree with the findings of the current study. Among female athletes, unipedal PC scores under all four the mCTSIB protocol conditions used were not significantly correlated to CODS. This finding remained the same when assessing CODS with either the 505-CODS total time or the COD deficit.

The results of this study indicated that postural control, as measured from a single leg mCTSIB protocol using the ISway accelerometery system, did not correlate with CODS. This should not discount the value of the mCTSIB and the ISway device as a clinical measurement, such as assessing which sensory system an athlete is more reliant on. However, the static method used to assess PC does not replicate the sport-specific movement of changing direction while at a high entry velocity. A dynamic postural control test which incorporates deceleration followed by a quick reacceleration would be a more suitable test to use for future research regarding this subject.

HYPOTHESIS THREE

The asymmetries between legs for change of direction speed ability would be significantly larger when using the COD deficit compared to using the total time of the 505-CODS test – **HYPOTHESIS ACCEPTED.**

The objective stated was to investigate the differences in leg imbalance percentages for CODS ability quantified using the 505-CODS test compared to using the COD deficit

The findings of the current study demonstrate that CODS ability is significantly different when turning with the dominant or non-dominant leg respectively. Both the CODS performances (505-CODS time and COD deficit) for turning with the dominant leg were significantly better than turning with the non-dominant leg. However, a significantly greater percentage of imbalance between legs in CODS performance was found when using the COD deficit compared to the 505-CODS total time.

The findings from Dos'Santos *et al.* (2018) are similar to the findings of the current study. To our knowledge the investigation by Dos'Santos *et al.* (2018) was the only other study which quantified the asymmetries in CODS ability using the COD deficit. As with the current study, Dos'Santos *et al*. (2018) found that the performances of CODS differed significantly between legs for both the 505-CODS test and the COD deficit ($p<0.0001$, $g=-0.53$ to -0.60). Significant differences in percentage imbalances between the two methods of assessing CODS (505-CODS total time and COD deficit), was also reported by Dos'Santos *et al.* (2018). This difference in imbalance between the two methods would subsequently impact the profiling and classification of an athlete's asymmetry.

The imbalance percentage between CODS performances of the current study were higher than what was reported in the study by Dos'Santos *et al.* (2018). The investigators found that among youth league netball players, an average imbalance of 2.3% existed for the performances in the 505-CODS test. As seen with the current study, the size of these imbalance percentages was significantly larger ($p<0.0001$, $g=1.03$) when assessed using the COD deficit, with a mean imbalance of 11.9% being reported by Dos'Santos *et al.* (2018). The significantly larger imbalance percentages determined using the COD deficit can possibly be attributed to the COD deficit being a more isolated measure of COD ability.

Using the COD deficit might be able to better show leg asymmetry in COD ability. From a coaching perspective, a >10% difference between leg might have implications for a player during a match, e.g. not being able to turn as quickly to one side. The 505-CODS test seems to not be able to finely discriminate imbalances in performance between legs.

HYPOTHESIS FOUR

There would be a significant difference in certain physical characteristics of netball players from different positional areas – **HYPOTHESIS ACCEPTED**

The objective stated was to explore whether players of specific positional areas display any significant differences among each other with regards to physical characteristics.

Limited research was found investigating the physical profile of netball players across different positions. The finding that the height and weight of female netball players differ significantly among positions is supported by Thomas *et al.* (2017). Among a group of youth academy level female netball players, the investigators found that defensive players (GK and GD) were significantly taller ($p \leq 0.05$; $d=1.6$) than mid-court players (C, WD and WA). In contrast to the current study, Thomas *et al.* (2017) did not find a significant difference in height between mid-court and the attacking players (GA and GS). Regarding body mass, the current study found that the players in the mid-court positions were significantly lighter than the attacking players. Thomas *et al.* (2017) reported that both attacking and defensive players had a significantly greater body mass ($p \leq 0.05$; $d=1.1$) compared to mid-court players.

The finding that there are significant differences in acceleration performances among netball players of different positions is also supported by the findings of Thomas *et al.* (2017). Over a straight-line sprinting (SLS) distance of 5m, the attacking players were significantly slower than the mid-court and the defensive players ($p=0.04$; $d \geq -0.9$). Concerning the 10m sprint times, the mid-court players were reported to be significantly faster than the attacking players ($p=0.01$; $d=-1.2$).

The current study found no significant difference between the CODS ability between players of different netball positions. This finding was true when CODS was assessed as either the 505-CODS test time and the COD deficit. This was in contrast with the findings of Thomas *et al.* (2017) who found that mid-court players had significantly faster 505-CODS test times than the defending and the attacking players for turns on the left and the right leg ($p \leq 0.03$; $d \geq 1.0$). It should be noted that the preferred side was not specified by Thomas *et al.* (2017).

According to the knowledge of the researchers, no previous study compared performances using the COD deficit among different netball positions. There was no significant difference between players of different netball positions for the 505-CODS. The ability to accelerate and change direction at a high entrance velocity has been indicated as a critical factor for mid-court players. The reason why no difference was found between positions is not clear. It could be that at the time of testing, players were still in the pre-season phase and position-specific training was not done. A possible explanation for the lack of a significant difference in the current study could be that the mid-court and attacking players were not able to decelerate effectively. Seeing as the 505-CODS test was found to favour those with superior acceleration ability, the finding that the attacking players were significantly slower during the sprinting times would suggest that a similar result would be seen in the 505-CODS time. The training staff could be advised to include drills for deceleration into the training of the mid-court players.

HYPOTHESIS FIVE

The netball players would display the most amount of postural sway during condition 4 (eyes closed and on the foam surface) of the mCTSIB protocol – **HYPOTHESIS ACCEPTED.**

The objective stated was to investigate which of the four single leg stance conditions of the mCTSIB protocol displayed the most amount of postural sway.

The testing condition which required the netball players to stand on the foam pad with closed eyes was found to have the most amount of postural sway. This was in line with the findings of Hammami *et al.* (2014) who tested the postural control ability of male athletes using the mCTSIB protocol with a bipedal stance. The current study found a significant difference between the static single leg postural control test done with opened eyes compared to closed eyes, while there was also a significant difference between the tests done on a firm surface compared to tests done on a foam surface. Hammami *et al.* (2014) reported a significantly more amount of sway in the conditions where vision was restricted (i.e. closed eyes) ($p<0.001$). The investigators also reported a significant increase in sway when tests were done on a foam surface compared to tests done on a firm surface ($p<0.001$).

As expected, the amount of Jerk recorded with the ISway system increased as the difficulty of the tests increased. For example, when visual and somatosensory inputs were prohibited, the amount of sway was found to be significantly more than when only visual or somatosensory inputs were prohibited. The lack of a significant difference between the condition with closed eyes on a firm surface compared to opened eyes on a firm surface would seem as if the players are equally dependent on somatosensory and visual sensory input for postural control during single leg stance.

HYPOTHESIS SIX

The spatiotemporal variables measured during the straight-line sprints would be significantly correlated to acceleration and change of direction speed measured as the 505-CODS test time, whereas no significant correlation would be found between the spatiotemporal variables and the COD deficit – **HYPOTHESIS ACCEPTED.**

The objective stated was to determine if selected spatiotemporal gait variables measured during straight-line sprinting were significantly correlated to acceleration ability and CODS performances

The current study's finding of a significant correlation between ground contact time (GCT) and performance in a SLS is similar to that of Nummela *et al.* (2007) who found a decrease in GCT as running velocity increased. Nummela *et al.* (2007) reported a large significant inverse correlation between GCT and velocity over 30m (r=-0.52), therefore a shorter GCT would likely result in a faster velocity being attained.

Lockie *et al.* (2011) reported that a shorter mean GCT was associated with faster acceleration performances. In the study by Lockie *et al.* (2011) male field sport athletes were divided into two groups (a faster and a slower group) based on the velocity reached over a 10m SLS. The results revealed that the faster field athletes had significantly shorter mean contact times than the athletes in the slower group at both the 5m and 10m splits (ES=1.18 and ES=1.00 respectively). Similarly, in another study Lockie *et al.* (2013) reported a significant relationship between GCT and the maximum velocity male field sport athletes for 5m (r=-0.506) and 10m (r=-0.477).

To the knowledge of the researchers no previous study has investigated the relationship between sprinting spatiotemporal gait variables and CODS. Therefore, there is no existing literature to which the results can be compared to. Coaches could emphasise "quick feet" during drills to create awareness of the importance of short contact times for short sprints.

SUMMARY OF MAIN FINDINGS

Previously, a lack of a significant relationship between acceleration ability and the COD deficit was argued to be evidence of isolating the ability to change direction. The main finding of the current study reveals how the base of this argument is flawed due to a significant inverse correlation being found between the COD deficit and the acceleration performances. However, the presence of a significant inverse correlation could still be argued to demonstrate how the COD deficit isolates the ability to execute a single directional change while at a high entrance velocity. Unlike the 505-CODS test time, the university netball players with faster acceleration abilities were likely to obtain a high COD deficit, thus taking longer to do a 180° direction change during a high entry velocity. Therefore, instead of favouring those with superior acceleration ability, as seen when using the 505-CODS time, the COD deficit is negatively affected if an individual is unable to slow down efficiently.

Executing a directional change while in motion requires a period of deceleration to change direction in a controlled manner before accelerating to a different direction. To change the momentum gained while at speed, adequate force needs to be produced to cause the deceleration and subsequent acceleration. An inverse relationship between COD deficit and acceleration shows that faster university netball players do not have the capabilities to produce enough force to rapidly overcome inertia. Thus, the time taken to decelerate enough to do a 180° cutting movement when at speed, takes longer for the faster netball players. Based on the findings of the current study, practitioners are encouraged to improve an athlete's ability to rapidly decelerate while running at high velocities, instead of simply improving acceleration.

The assessment of CODS by means of the total time taken to complete a CODS test could falsely lead practitioners to focus on improving an athlete's acceleration ability to ultimately improve their CODS ability. If an athlete is not able to effectively control his/her momentum when changing direction, as seen with the netball players of the current study, the improvement of acceleration ability would be counterproductive to the ultimate desired improvement of CODS ability. Instead, slowing down in a quick and controlled manner should be emphasised during training. Training protocols which include COD drills and plyometric exercises could assist in the improvement of the lower limb neuromuscular qualities. The lack of a significant correlation CODS performances and postural control, as measured by the mCTSIB protocol, indicates that static balance exercises are unlikely to improve an athlete's ability to change direction. The single leg stance with eyes closed, done on an uneven surface, is an example of such a static balance exercise.

The results of the current study demonstrated that the netball players had significantly better CODS performances when pivoting with their dominant limb compared to their non-dominant limb. This was found for both the total time of the 505-CODS test and the COD deficit as assessments of CODS ability. Therefore, researchers and practitioners are advised to use CODS tests which assess the turning ability of each limb independently to establish directional dominance and CODS asymmetries. Using the COD deficit to quantify asymmetries in CODS to establish directional dominance produces substantially higher percentage of imbalances between limbs, compared to quantifying asymmetries based on the total completion time the 505-CODS test. The low percentage of imbalances between limbs when using the time of the 505-CODS could mask possible deficiencies in COD ability. This could potentially cause practitioners to misinterpret an athlete's symmetry in COD ability between legs. Quantifying and profiling the netball players' asymmetries in CODS ability with the COD deficit, identified a much greater proportion of players demonstrating imbalances around 10-15%. This range represents a potentially problematic asymmetry, as stated previously.

According to the researchers' knowledge, the current study was the first study to determine if spatiotemporal gait variables during a straight-line sprint (SLS) were correlated to the COD deficit. The current study found that stride frequency (SF) and ground contact time (GCT) were significantly correlated to the time taken to complete the 505-CODS test. There was no significant relationship found between any spatiotemporal gait variables and the COD deficit performances. Additionally, the current study found that a small GCT and a high SF were associated with superior acceleration performances. These findings, along with the known link between average sprinting speed (average speed = SL x SF), further demonstrate how performances in CODS tests assessed as the total time of completion are influenced by acceleration ability. The absence of a significant correlation between sprinting spatiotemporal gait variables and the COD deficit indicates that the COD deficit isolates the ability to change direction while at a high entrance velocity.

CONCLUSION

The COD deficit appears to provide an isolated assessment of the ability to change direction by eliminating the favouring influence of a superior acceleration ability. Strength and conditioning coaches can incorporate the COD deficit into their performance assessments with ease, as no additional sophisticated equipment is required and the 10m sprint is commonly included in performance assessments.

Instead of making use of only one method of assessing CODS, practitioners are advised to make use of the COD deficit along with the total time of a CODS test. The COD deficit could be helpful for coaches to determine if an athlete or a team is able to efficiently do a 180° COD with a high entrance velocity. Despite the flaws of assessing an athlete's COD ability as the total time taken to complete a CODS test, short and simple CODS tests such as the 505-CODS test could still be useful to coaches. Furthermore, the movements present in these types of CODS tests are similar to those experienced in invasive team sports such as netball. Accelerating to a point, decelerating to change direction in a controlled manner and reaccelerating to a new direction are all examples of these movements.

Future research is required to confirm the validity of the COD deficit and to create norms from athletes of varying sporting levels and backgrounds. With established norm values, a scale could be developed which could inform coaches whether an athlete is able to effectively control his/her momentum when changing direction. For example, if COD deficit is above a certain score the coaches could implement training programs which focus on improving the control of momentum when changing direction. In contrast, if COD deficit is below a certain score it could inform practitioners that training programs which aim to improve acceleration could be correctly incorporated without negatively effecting COD ability.

When assessing CODS, researchers and practitioners are advised to perform CODS tests which measure the turning capabilities of each leg, irrespective of the other. This could help establish a directional dominant side and identify problematic asymmetries. Using the COD deficit could serve as a useful tool to assist coaches in spotting imbalances in the turning ability between legs to inform future training.

LIMITATIONS

A limitation to this study was that testing was only done at one point during the season (pre-season). The strength of the relationship between bio-motor abilities has previously been shown to fluctuate through the course of a season. This study was limited to investigating a homogeneous group high-level netball group from one club. Results from the study cannot be extrapolated to other team sports or netball players from other levels.

FUTURE STUDIES

Future research is required across different athletic populations using the COD deficit to provide information on how the COD deficit differs between athletes of varying sporting disciplines and performance levels. The COD deficit should be assessed among participants of different populations (i.e. gender, age). Future studies should assess the potential relationship between COD deficit and lower limb muscle qualities. The effect of specific training programmes on the performance of COD deficit should be explored in future studies. It is recommended that future studies specifically investigate eccentric strength due to it being an important aspect of the braking phase prior to the COD. Studies should also investigate the correlation between CODS performances and sport specific dynamic postural control tests. The relationship between CODS and dynamic PC tests are not clear yet, which is an area requiring further research. Long term investigations throughout the period of a season should be done to assess how the strength of the relationship varies throughout the season as athletic conditioning is improved. Furthermore, an investigation on the technical determents of the COD deficit should be investigated to inform coaches with regard to verbal instructions which could assist athletes in improving the ability to change direction while at speed. The relationship between the COD deficit and the entry and exit velocities during a COD should be investigated in future studies.

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APPENDIX A

STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

INFORM CONSENT

Title of Research Project: The relationship between change of direction ability, acceleration and postural control of female university netball players.

You are asked to participate in a research study conducted by **JP Lombaard** (MSc in Sport Science) under the supervision of **Prof R. E. Venter**, from the **Department of Sport Science** at Stellenbosch University. You were selected as a possible participant in this study because you are a healthy netball player and completed pre-season club strength and conditioning program.

1. AIM OF THE STUDY

The aim of this study to determine the relationship between selected bio-motor abilities among netball players.

2. TESTING

You will have two testing sessions. The first session is for the running tests which will be in the Coetzenburg centre (about half an hour). The third session is the postural control test at the Department of Sport Science (15 min). The following tests will be performed before the training program and after the training programme. All tests will be performed barefoot and with your netball shoes.

2.1. Acceleration test

You will run as fast as possible over a 20m distance. The timing for 5m, 10m and 20m will be recorded to the nearest 0.01 second. You will complete two trials and the fastest time over 10m will be used as the final result.

2.2. 505 Change of direction speed test

Timing lights will be set up at 10 m from the starting line and 15 m from the turning point. You will start from a standing position and sprint through the timing gate to the turning point. You will immediately turn and accelerate back to the starting line through the timing gates. You will be instructed to turn on the left and the right foot. Time to the nearest 0.01 sec will be recorded and the fastest time of two trials for each foot will be final score.

2.3. Postural Control / Balance

A small devise will be strapped to your back and you will be asked to stand barefoot on a single leg for 30secs. The trial will be for the other leg. The test is in four different categories: standing with eyes open on a firm surface; standing with eyes closed on a firm surface; standing with eyes open on a foam and standing with eyes closed on foam.

3. POTENTIAL RISKS AND DISCOMFORTS

There will be no serious risks involved in the study. The potential risks will be minimized as much as possible by thoroughly explaining the procedure to you and carefully monitoring all the test. All measurements are within your health and fitness capacity. All measurements are non-invasive, for example no drawing of blood.. There will be a basic life support (BLS) qualified health-care professionals available at all times to perform cardiopulmonary resuscitation (CPR). Should any emergency arise, you will be stabilized and then immediately transported to the emergency room at Stellenbosch Medi-Clinic.

4. PAYMENT FOR PARTICIPATION

As a participant you will not receive any financial reimbursement or payment to participate in the study. Any financial cost in terms of transportation to the testing lab or any other related logistics will be covered by the investigator.

5. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of withholding the names of the participants and only using numerical codes to represent subjects. This means that reported results will only include codes and no names at all. Recorded data will be filed and stored in a locked room and on a password protected personal computer and will only be accessed by the researcher and promoter. If your coach wants access to your results, you will be asked to provide written consent. All information obtained in the study will not be disclosed, unless published, in which case it will be treated as not to identify anyone.

6. PARTICIPATION AND WITHDRAWAL

You can choose whether to take part in this study or not. If you volunteer to participate in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Participation will be discontinued if you fail to comply with the testing protocol. Your consent to participate in this research will be indicated by your signing and dating of the consent form.

7. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact the researcher JP Lombaard (076 364 2603; 17734533@sun.ac.za) or the promoter, Prof. R. E. Venter (021 808 4915 or rev@sun.ac.za).

8. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

STELLENBOSCH UNIVERSITEIT

TOESTEMMING OM AAN NAVORSING DEEL TE NEEM

Titel van Navorsingsprojek:

Jy word uitgenooi om aan 'n navorsingsprojek deel te neem. Hierdie studie word deur JP Lombaard (MSc in Sportwetenskap) onder die leiding van Prof R. E Venter, van die Departement Sportwetenskap aan Universiteit Stellenbosch gedoen. Jy is as moontlike deelnemer gekies omdat jy 'n gesonde netbalspeler is en jou klub se voorseisoen krag- en kondisioneringsprogram gedoen het.

1. DOEL VAN DIE STUDIE

Die doel van die studie is om die verhouding tussen die biomotoriese vaardighede in netbalspelers kan verbeter.

2. TOETSING

Jy sal twee toetssessies hê. Die eerste sessie is die hardlooptoetse is in die Coetzenburgsentrum (ongeveer 'n halfuur). Die tweede toetssessie is die balanstoets by die Departement Sportwetenskap (15 minute). Die volgende toetse sal voor en na die oefenprogram program gedoen word:

2.1. Versnellingstoets

Jy sal volspoed oor 'n afstand van 20m hardloop. Jou tyd oor 5- 10- en 20m sal tot die naaste 0.01sek aangeteken word. Jy sal twee hardlooppogings kry en jou vinnigste tye sal as jou finale tyd aangeteken word.

2.2. 505 Ratsheidtoets

Spoedligte sal 10m vanaf die beginpunt en 15m vanaf die omdraaipunt opgestel word. Jy sal uit 'n staande posisie begin en so vining as moontlik deur die spoedligte tot by die draaipunt hardloop. Jy sal dadelik omdraai en terug versnel na die begin deur die spoedligte. Jy sal met jou linker- en regtervoet omdraai. Tyd sal tot die naaste 0.01 sek gemeet word en die vinnigste tyd van die twee beurte op elke voet sal as finale telling geneem word.

2.3.Posturale Beheer/ Balans

'n Versnellingsmeter sal op jou rug geplaas word. Jy sal gevra word om vir 30 sek kaalvoet in die volgende situasies te staan: oop oë en toe oë op die grond; oop oë en toe oë op 'n dik rubbermat.

3. MOONTLIKE RISIKOS EN ONGEMAK

Daar is geen ernstige risiko's aan die studie verbonde nie. Jy mag ongemak ervaar gedurende die toetssessies omdat jy nie gewoond mag wees aan die toetse of oefeninge nie. Moontlike risiko's sal sover moontlik verminder word deurdat die prosedures aan jou verduidelik sal word en jy gemonitor sal word.

Alle metings is nie-indringend, bv geen bloedtoetse of vingerprikke nie. Indien enige besering of negatiewe insident voorkom, sal die toetsing onmiddellik gestaak word en sal jy noodhulp, ontvang. Indien ʼn noodsituasie ontstaan, sal jy gestabiliseer word en onmiddellik na die noodeenheid by Stellenbosch Medikliniek geneem word.

4. BETALING VIR DEELNAME

Geen betaling vir deelname aan hierdie studie word aan enige deelnemer gedoen nie. Daar is ook geen finansiële uitgawes vir jou betrokke vir deelname in hierdie studie nie. Enige finansiële koste wat verband hou met vervoer sal deur die navorser betaal word.

5. VERTROULIKHEID

Enige inligting wat tydens hierdie studie verkry word en wat jou kan identifiseer, sal vertroulik gehou word. Dit sal net met jou toestemming bekend gemaak word of soos die wet dit vereis. Vertroulikheid sal behou word deur gebruik te maak van ʻn getalle sisteem wat ʻn nommer aan alle resultate koppel. Dus sal jou naam nooit bekend gemaak word aan enige party nie. Data sal veilig toegesluit word in ʻn kantoor, waar dit vir ʻn minimum van drie jaar gehou word indien jy enige verifikasie of bewys van enige gepubliseerde informasie en uitkomstes sou verlang. Behalwe vir die navorsers en die studieleier, sal geen ander persoon toegang tot enige data hê nie. Indien jou afrigter jou data wil hê, sal jy gevra word om skriftelik toestemming te verleen. Daar is ʻn moontlikheid dat hierdie studie gepubliseer mag word in ʻn tydskrif.

6. DEELNAME EN ONTTREKKING

Deelname aan hierdie studie is vrywillig en kan jy die uitnodiging om deel te neem, weier. As jy vrywilliglik instem, kan jy enige tyd van die studie onttrek sonder enige nagevolge. Jy mag ook weier om enige van die vrae te beantwoord en nog steeds aan die studie deelneem. Die navorsers mag jou van die studie onttrek as enige omstandighede dit verg.

7. IDENTIFIKASIE VAN NAVORSERS

As jy enige vrae het, moet asseblief nie huiwer om die volgende persone te kontak nie: JP Lombaard (076 364 2603; 17734533@sun.ac.za) of promoter Prof. R. E. Venter (021 808 4915 of rev@sun.ac.za).

8. REGTE VAN DEELNEMERS

Jy mag jou toestemming enige tyd tydens die studie onttrek en jou deelname staak sonder enige nagevolge. Jou deelname aan hierdie navorsingsprojek oortree geen wetlike eise, regte of drastiese maatreëls nie. Kontak gerus Me. Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] by die Afdeling van Navorsingsontwikkeling vir enige vrae oor jou regte as deelnemer in navorsing.

APPENDIX B

Netball Bio-motor testing: Data Sheet

Tag no: _______________

Personal Details

Surname		**Name**	
DOB		**Dominant side (L/R)**	
Team		**Playing Position**	
Cell no.		**Email**	

Anthropometry

Weight (kg)		**Height (cm)**	

20m straight-line sprint (s)

5m	**10m**	**20m**
(1)	(1)	(1)
(2)	(2)	(2)
(3)	(3)	(3)

505-CODS test (s)

Right turn	**Left turn**
(1)	(1)
(2)	(2)
(3)	(3)

Have you suffered any lower limb injuries over the last 6 months? If yes, please specify the injury and how long ago it occurred?

Yes ______ No _______

APPENDIX C

Name & Surname: XXX Date: 20/03/2015

Testers: XXX

The postural control tests we conducted helps to determine which sensory system (visual, somatosensory, or vestibular) the athlete relies most on to maintain their balance. As a result we can identify strengths and weakness among the systems to improve balance and minimize the risk of injury.

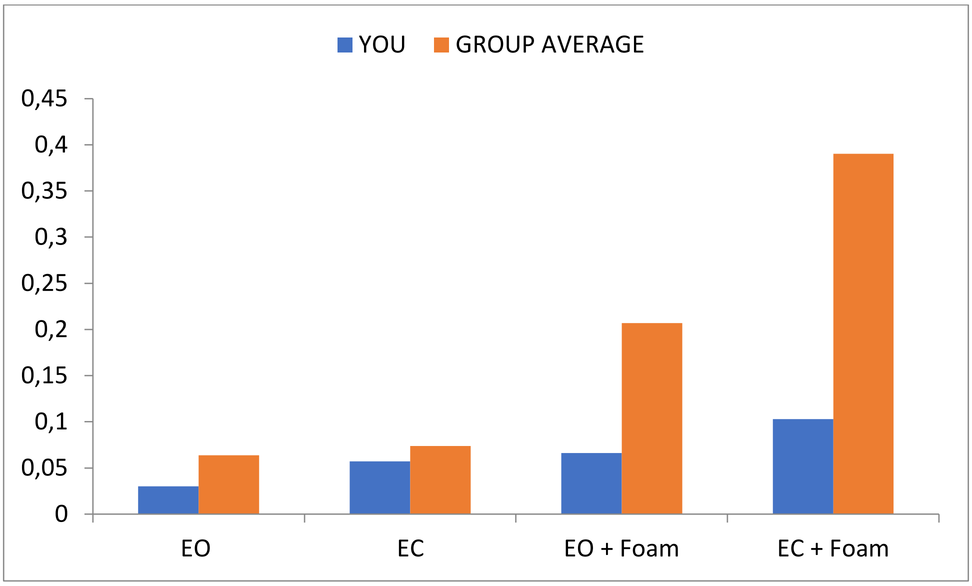
In summary: if you are visually dependent you will see a higher score on conditions where the eyes are closed, if you depend on surface or somatosensory input you will have a higher score in conditions where you are standing on the foam surface, and if you have vestibular loss you will be more unstable in conditions where you can't rely on vision or somatosensory inputs i.e. when your eyes were closed and you were standing on the foam surface. A higher score indicates more postural sway which shows a more unstable and weaker balance performance.

Results

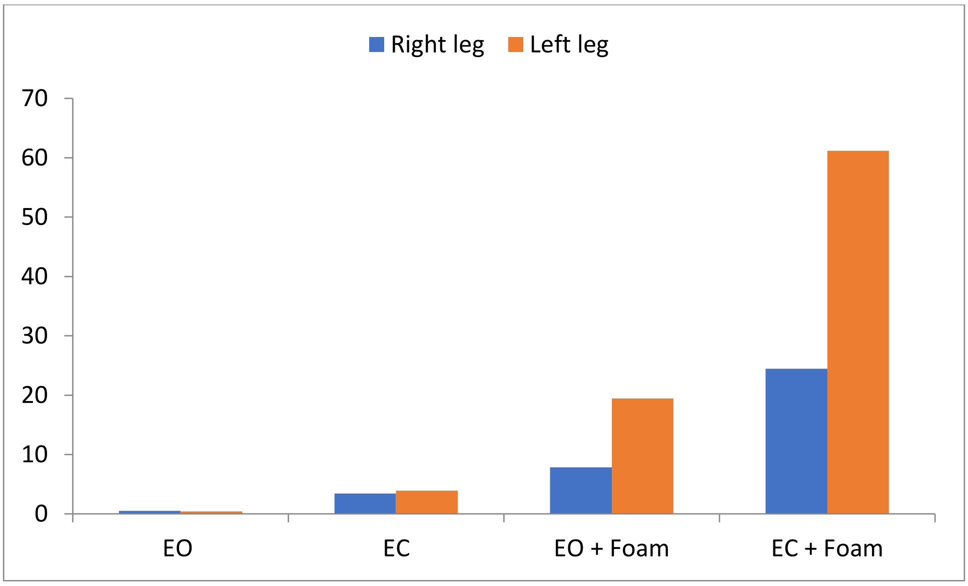
We tested 12 conditions, with each trial lasting 30 seconds.

Condition	Athletes Score	Group Average
Firm surface, both legs, eyes open	0.030	0.043
Firm surface, both legs, eyes closed	0.057	0.045
Foam surface, both legs, eyes open	0.066	0.184
Foam surface, both legs, eyes closed	0.103	0.590
Firm surface, right leg, eyes open	0.520	1.324
Firm surface, left leg, eyes open	0.401	1.372
Firm surface, right leg, eyes closed	3.416	41.546
Firm surface, left leg, eyes closed	3.918	14.653
Foam surface, right leg, eyes open	7.861	7.631
Foam surface, left leg, eyes open	19.465	9.977
Foam surface, right leg, eyes closed	24.472	166.937
Foam surface, left leg, eyes closed	61.207	86.198

Sensory organisation overall



Sensory organisation single legs



Comments

Your results showed that you constantly scored lower than your team mates in the overall condition. These results give us no additional information other than the normal increase in sway over the conditions, but also that your sensory integration is quite developed. When you have a wide base of support your balance is very good.

The higher score when you were on the foam in the single leg conditions show that you depend on your somatosensory inputs to maintain your balance. However, your left leg consistently shows an increase in sway, as a result you struggled to maintain your balance when on your left leg compared to your right. These results are interesting considering you have sustained right ankle injuries and also have abnormal ankle anatomy. It can of course indicate that you have spent some time working and focussing on your right, and in the process neglected to give your left side equal amount of attention, and therefore it performs weaker on the tests.

Exercises

The aim of the exercises will be to improve your balance in single leg stance, specifically on the left leg. All exercises must be performed barefoot. Exercises include progressions which should only be tried once you have mastered the basic exercise. If there are more than one balance progression, do each one separately and then try both progressions together; then only add the general progression. Head movements include movements of the head going up and down, side to side and diagonal (right down to left up and visa versa). Head movements without eye movements mean that your eyes remain fixed and focus on a central place while your head moves, whereas as head movements with eyes movements mean your head and eyes move together. Slow and controlled quality movements are the main aim; speed is only added when told to do so.

Equipment you will need: Netball, medicine ball, weights, Bosu, step, elastic band & slider/paper plate/ socks

If you have any questions, don't hesitate to contact us. Should you wish we can do a more in-depth analysis and rehabilitation and strengthening specific program.

Kind regards