

THE RELATIONSHIPS BETWEEN ECCENTRIC STRENGTH AND POWER WITH DYNAMIC BALANCE IN MALE FOOTBALLERS

Marc Jon Booysen
Student number 564989

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Medicine in the field of Sports Science

15 May 2014

Declaration

I, Marc Jon Booysen, declare that this research report is my own work. It is being submitted in partial fulfilment of the degree of Master of Science in Medicine in the field of Sports Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

A handwritten signature in black ink, appearing to read 'M Booysen'.

 (Signature of candidate)

15 May 2014

ABSTRACT

Introduction: This study sought to determine the relationships between eccentric strength and power of the lower extremity with dynamic balance in male football players. Footballers with superior balance, kick more accurately, have a possible reduced risk of injury and faster agility times. However, the relationship between eccentric strength and power with dynamic balance remains unresolved.

Methods: Fifty male footballers (university; $n = 27$ and professional; $n = 23$) volunteered to participate in the study and performed the Y-balance Test, eccentric isokinetic knee extensor and flexor testing and the countermovement jump.

Results: The university group demonstrated significant positive correlations between mean eccentric peak torque to body weight of the knee extensors and composite score in the Y-balance test ($r = 0.42$, $p = 0.03$) and between eccentric peak torque to body weight of the knee extensors of the non-dominant leg with normalised reach distance in the Y-balance test on the non-dominant limb ($r = 0.50$, $p = 0.008$). In the professional group, countermovement jump height was significantly correlated with composite score in the Y-balance test ($r = 0.52$, $p = 0.02$). Furthermore, countermovement height was positively correlated to normalised reach distance in the Y-balance test on the non-dominant limb in the university ($r = 0.4$, $p = 0.05$) and professional ($r = 0.56$, $p = 0.006$) groups, respectively.

Conclusion: Moderate positive relationships exist between eccentric strength of the knee extensors and dynamic balance in the university group and between power and dynamic balance in the professional group. These findings may be due to different coordination strategies between the groups to maximize reach distance. Both groups demonstrated a significant relationship between countermovement jump height and reach performance on the non-dominant leg. In footballers, different neural control strategies may develop between the limbs due to their constant use of their non-dominant leg to stabilise whilst executing a

kicking action. Due to these significant relationships, a longitudinal study measuring the effects of strength and power training on dynamic balance in footballers is required to ascertain cause and effect.

Acknowledgements

I would like to acknowledge the following people for their assistance in this research report;

The football players who volunteered their time and effort for testing and the team coaches who allowed me access to their players.

My supervisors, Mr Philippe Gradidge and Mrs Estelle Watson for their advice and support through the data collection process. Their assistance was invaluable in helping me put this research report together.

Professor Demitri Constantinou for his assistance throughout the research process.

Professor Rosemary Crouch for her advice and help in the initial stages of the writing up of this report.

TABLE OF CONTENTS

Title page	
Declaration	2
ABSTRACT	3
Acknowledgements	5
List of figures	9
List of tables	10
Definition of terms	11
Abbreviations	14
CHAPTER ONE.....	16
1. INTRODUCTION.....	16
1.1 Problem statement	17
1.2 Research aim.....	18
1.3 Research objectives.....	18
CHAPTER TWO.....	19
2. LITERATURE REVIEW	19
2.1 Introduction	19
2.2 Balance.....	19
2.2.1 The maintenance of balance:	19
2.2.2 Balance strategies	21
2.3 Balance in the game of football.....	22
2.4 The relationship between power and dynamic balance	23
2.5 The relationship between eccentric strength and dynamic balance.....	25
2.6 Summary	28
CHAPTER THREE	29
3. METHODS	29
3.1 Study design	29
3.2 Participants	29
3.2.1 Participant inclusion criteria.....	30
3.2.2 Participant exclusion criteria	30
3.3 Procedures and instrumentation:	32
3.3.1 Anthropometric measurements:.....	32

3.3.2 Dynamic balance	33
3.3.3 Counter Movement Jump (CMJ):.....	36
3.3.4 Eccentric strength testing	37
3.4 Data analysis.....	38
CHAPTER FOUR	40
4. RESULTS	40
4.1 Physical characteristics of the participants:	40
4.2 The performance characteristics of the university and professional groups.....	41
4.2.1 Dynamic balance	41
4.2.2 Eccentric strength of the knee extensors.....	42
4.2.3 Eccentric strength of the knee flexors.....	42
4.2.4 Power	43
4.3 Relationships between eccentric strength of the knee extensors and dynamic balance	43
4.3.1 University group	43
4.3.2 Professional group	45
4.4 Relationships between eccentric strength of the knee flexors and dynamic balance	45
4.4.1 University group	45
4.4.2 Professional group	45
4.5 Relationships between power and dynamic balance	46
4.5.1 University group	46
4.5.2 Professional group	46
4.6. Summary of correlations.....	48
4.7 Coefficient of variance for isokinetic testing	49
CHAPTER FIVE	51
5. DISCUSSION	51
5.1 Introduction	51
5.2 Eccentric strength of the knee extensors and dynamic balance	52
5.3 Eccentric strength of the knee flexors and dynamic balance	55
5.4 Power and dynamic balance	56
5.5 The relationship of power and eccentric strength with dynamic balance on the dominant versus non-dominant limb.....	58
5.6 Limitations	60

5.7 CONCLUSION	61
5.8 PRACTICAL APPLICATIONS	62
5.9 Future research recommendations	63
REFERENCES:.....	64
APPENDIXES	76
Appendix A: Diagrammatic representation of the maintenance of balance	76
Appendix B: Participant's information sheet.....	77
Appendix C: Ethics approval	79
Appendix D: Ethics amendment	80
Appendix E: Participant's medical questionnaire:	81
Appendix F: Consent form.....	83
Appendix G: consent form for professional team	84
Appendix H: Data collection sheet:.....	88

List of figures

Figure 1: Flow chart depicting the data collection process.....	31
Figure 2: Anterior reach in the YBT on the left leg.....	35
Figure 3: Post medial reach in the YBT on the left leg.....	35
Figure 4: Post lateral reach in the YBT on the left leg.....	36
Figure 5: The relationship between mean eccentric strength of the knee extensors with composite reach score (YBT%) of the university group (n = 27).....	44
Figure 6: The relationship between eccentric strength of the non-dominant leg knee extensors with normalised reach distance on the non-dominant limb (YBT-NDL%) in the university group (n = 27).....	44
Figure 7: The relationship between power with normalised reach distance on the non-dominant leg (YBT-NDL%) in the university group (n = 27).....	46
Figure 8: The relationship between power with composite reach score (YBT%) in the professional group (n = 23).....	47
Figure 9: The relationship between power with normalised reach distance on the non-dominant leg (YBT-NDL%) in the professional group (n = 23).....	47

List of tables

Table 1: Physical characteristics of the participants.....	40
Table 2: Physical characteristics of the university and professional groups.....	41
Table 3: Dynamic balance characteristics of the participants.....	41
Table 4: Eccentric strength of the knee extensors of the participants.....	42
Table 5: Eccentric strength of the knee flexors of the participants.....	42
Table 6: Countermovement jump height of the participants.....	43
Table 7: Summary of correlations between power and eccentric strength and YBT composite reach.....	48
Table 8: Summary of correlations between power and eccentric strength of the dominant leg and normalised reach on the dominant leg.....	48
Table 9: Summary of correlations between power and eccentric strength on the dominant leg and normalised reach on the non-dominant leg.....	49
Table 10: Coefficient of variance values for isokinetic testing of the knee flexor muscle group.....	49
Table 11: Coefficient of variance values for isokinetic testing of the knee extensors muscle group.....	50

Definition of terms

Balance: Balance is a broad term which describes the movements of the body posture to prevent a fall (1). Balance can also be described as the ability to maintain the body's centre of gravity (COG) vertically over the base of support (BOS) (2).

Base of support: This is the area outlined by are the contact areas of the body (usually the feet) with the support surface. If two feet are in contact with the ground, the BOS includes the contact areas of both feet and the area between them. However, if one foot is in contact with the ground the BOS is the contact area of the foot (3).

Centre of gravity: The vertical projection of the centre of mass (COM) onto the ground (1).

Centre of mass: In a multi-segmented body, the COM is the sum of the mass of each segment and the location of the COM moves depending on the configuration of the segments (3) and is the variable controlled by the balance control system (1).

Centre of pressure: This is the location of the vertical ground reaction force (GRF) vector and represents the average of all the pressures over the surface of the area in contact with the ground (1). The location of the centre of pressure (COP) is direct reflection of the neural control of the musculature (1).

Coefficient of variance: Coefficient of variance (CV) is the standard deviation expressed as a percentage of the mean. The lower the CV the less variability in performance of the isokinetic repetitions and more reliable the data (4).

Close-kinetic chain: Close-kinetic chain (CKC) movements occur when the distal segment of the lower extremity is fixed (i.e. the foot is weight-bearing on the ground) (5).

Concentric contraction: Concentric contractions occur where the resultant muscle torque is greater than the load torque causing the muscle to shorten and lift a load (6).

Dynamic balance: Dynamic balance can be described as the ability to maintain the COG within the BOS whilst performing a movement (7) or a functional task (8, 9).

Eccentric contraction: A lesser studied component of the strength spectrum is eccentric strength (10) and is where the force or torque that a muscle can exert is less than the resistance or load torque, the activated muscle lengthens and performs an eccentric contraction to lower the load (6). Eccentric strength would therefore be the maximal amount of force a muscle can resist.

Isometric contraction: When the muscle and load torques are equal and opposite and the load does not move, an isometric contraction occurs (6).

Limits of stability: The area over which an individual can move their COM and maintain equilibrium without changing their BOS (11).

Open-kinetic chain: Open-kinetic chain (OKC) movements in the lower extremity occur when the distal segment is mobile (5) (i.e. not weight-bearing).

Perturbation: Is a destabilizing event that may cause a loss of balance which may include an external push or shove or a self-initiated movement (12). An internal perturbation is the most common perturbation which is voluntarily initiated and occur from different orientations of the body due to movement of the limbs or COM (1).

Postural control: The act of maintaining, achieving or restoring a state of balance during any posture or activity (13).

Postural equilibrium: Involves the coordination of movement strategies to stabilise the centre of mass during disturbances of stability (11).

Power: Power is defined as the amount of work produced per unit time or the product of work and velocity (14).

Reach performance: Normalised reach distance in the Y-Balance test (YBT)

Static balance: Static balance is the ability to maintain the body's COG within the BOS in a quiet upright position during standing (12).

Strength: Strength can be defined as the maximal force or torque a muscle or muscle group can generate (15).

Stretch shortening cycle: Refers to the ability to store and transfer energy from an eccentrically stretched muscle tendon complex to the concentric phase (16).

Abbreviations

ACL: Anterior cruciate ligament

BESS: Balance Error Scoring System

BOS: Base of support

COG: Centre of gravity

COM: Centre of mass

COP: Centre of pressure

CMJ: Countermovement jump

CMJ_H: Countermovement jump height

CV: Coefficient of variance

DL: Dominant leg

EMG: Electromyography

IQR: Inter-quartile range

LOS: Limits of stability

MVIC: Maximal voluntary isometric contraction

NCAA: National Collegiate Athletic Association

NDL: Non-dominant leg

PSL: Professional Soccer league

PT/BW: Peak torque to body weight

ROM: Range of motion

SAFA: South African Football Association

SEBT: Star Excursion Balance Test

SSC: Stretch-shortening cycle

YBT: Y-Balance Test

YBT%: Composite score in the YBT or normalised reach distance of both legs combined

YBT-DL%: Normalized reach on the dominant leg in the YBT

YBT-NDL%: Normalised reach on the non-dominant leg in the YBT

1RM: One repetition max

CHAPTER ONE

1. INTRODUCTION

Balance is regarded as the foundation for mobility (12) and is a prerequisite for purposeful movement (3). The process of maintaining balance is complex and involves multiple neurological pathways in order to maintain postural equilibrium (17). Dynamic balance can be defined as the ability to maintain the centre of gravity (COG) within the body's base of support (BOS) whilst performing an intended movement (7) and is a vital component of performance in the game of football (18). The football match is characterised by intense, explosive activity including jumping, kicking, directional changes and maintaining balance during physical encounters against the opposition (19, 20). Many of these skills are executed from a single leg (8, 21), resulting in the stability of the stance foot becoming a crucial element in optimal performance (21, 22). An inability to remain balanced can disturb force production, attenuate performance (3), and potentially increase the risk of injury (23-26). Elite football players demonstrate better balance capabilities than their non-elite peers (7, 21) and when compared with other sports, both genders of football athletes have demonstrated more superior single leg balance (8, 27).

High-threshold motor units are essential for intense athletic competition and for movements that require high levels of muscular power (6). Thus, it would seem plausible that athletes with more power would perform better in dynamic balance testing. Erkmen et al. (28) demonstrated that there was a significant relationship between power and single-leg balance in football players, whilst Johnson and Woollacott (29) observed that power trained athletes responded faster to external perturbations than endurance trained athletes. In comparison, Muehlbauer et al. (30) found a non-significant association between dynamic balance and

counter movement jump (CMJ) height in both healthy young and middle-aged adults, concluding that these abilities may be independent of each other.

The role of an eccentric contraction in functional movement is to absorb, decelerate and stabilize the forces imposed on the body's centre of mass (COM) (10, 31). There are only a few investigations in the literature examining the relationship between eccentric strength and performance (10). Muehlbauer et al. (30) reported that the variables of isometric strength and dynamic balance were independent of each other, whilst Thorpe and Ebersole (32) observed no significant relationship with concentric strength and dynamic balance in female non-football and female football players. Similarly, Paterno et al. (33) concluded that concentric knee extensor strength did not predict reach performance in the star excursion balance test (SEBT) in healthy young athletes. However, there is evidence to suggest that eccentric strength of the lower extremity plays an important role in dynamic balance. For example, Norris et al. (34) observed high activation levels of the vastus medialis, during the lowering phase of the SEBT. Recently, Lockie et al. (35) observed that stronger knee extensors in both contraction modes were associated with better dynamic balance in male team sport athletes.

1.1 Problem statement

Superior dynamic balance is critical to the football player (18) (19) where stability of the stance foot is related to kicking accuracy (22). However, the relationship between eccentric strength and power with dynamic balance in young male football players remains unresolved. A better understanding of these neuromuscular factors may help advance current balance training interventions in footballers, possibly improving performance (35) and preventing injuries.

1.2 Research aim

To determine the relationships between eccentric strength and power of the lower extremity with dynamic balance in male football players.

1.3 Research objectives

- 1.3.1 To determine the relationship between eccentric strength of the knee extensors and dynamic balance in the Y-Balance Test.
- 1.3.2 To determine the relationship between eccentric strength of the knee flexors and dynamic balance in the Y-Balance Test.
- 1.3.3 To determine the relationship between lower extremity power and dynamic balance in the Y-Balance Test.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

The purpose of this literature review will be to briefly describe how balance is maintained, highlight important research into balance ability within footballers, and then examine the literature on the relationship between eccentric strength and power with dynamic balance.

2.2 Balance

Balance is regarded as the foundation for mobility and functional independence throughout an individual's life (12) and plays an important part in maintaining a stable base of support (BOS) whilst a person is in motion (36). In modern sport, superior balance abilities have been shown to be related to better speed, agility and more accurate performance in sports (22, 36-38) and a reduced risk of injury (23-26). More specifically, low preseason balance ability and balance asymmetry has been found to contribute to the likelihood of increased risk of injury (23, 24) as well as a reduction in an athlete's ability to rapidly change direction (36).

2.2.1 The maintenance of balance:

The human body is said to be balanced if an individual's body weight and ground reaction force (GRF) are of equal magnitude, and the centre of pressure (COP) is located directly below the COG (3). In this biomechanical arrangement, the net forces or moments acting on the body are zero and the body is in equilibrium (3). During any movement where an individual is in an upright position, the body's COG will shift around the BOS (3). If the COG remains within the BOS, coordinated muscular activity involving the ankles, knees and

hips can relocate the COP and return the COG to a more central location within the BOS (3). This requires a certain amount of strength and reaction time (3). The maintenance of balance is a complex process involving multiple neurological systems (17) (appendix A). This includes sensory afferent information, from the visual, vestibular and somatosensory organs providing information regarding the position and motion of the body in relation to its surroundings (12, 17). Furthermore, integration of this sensory information is needed to organise the appropriate neuromuscular response, involving activation of the musculoskeletal system to coordinate movement strategies along the joints of the kinetic chain in order to maintain balance against gravity (12, 17). Therefore, a person can have impaired balance if either the position of the COG relative to BOS is not accurately sensed, and/or the automatic movements required to bring the COG back to a balanced position are not timely or effectively coordinated (39) or the person lacks adequate muscle strength or nerve functioning (12).

Three areas of human activity exist where postural control is important (13):

1. The maintenance of a specified posture as in static balance or standing motionless (13);
2. Voluntary movement (i.e. internal perturbation from the movement of one's limb which is the most common perturbation and occurs due to the various orientations of the body such as reaching, turning, bending (1, 13), and
3. Reaction to an external disturbance or perturbation (13).

In order to maintain balance in the presence of perturbations, postural control strategies can either be reactive (compensatory) or predictive (anticipatory) (13) or a combination of both. Anticipatory (or proactive) postural adjustments operate as a feed forward control, preceding

internal disturbances caused by voluntary actions (1, 40) and results in a shifting of the body's COG to a more appropriately balanced location in order to maintain balance during the selected movement (40). Importantly, these are the main sources of balance disturbances (40). In contrast, reactive balance control involves a muscular response following an unpredicted disturbance to stability (12, 13). Maintaining balance in functional daily situations, involves elements of both anticipatory and reactive balance control (12).

2.2.2 Balance strategies

Three joint systems, namely the ankle, knee and hip joints, are located between the BOS and the COG, form an important part of the neuromuscular response in balance control of the closed kinetic chain (17). Depending on the intensity of the perturbation that threatens balance, motion at one or more of these three joints can form part of a coordinated movement strategy along the kinetic chain that brings the COG back to a balanced position within the BOS (17). Factors that determine the intensity of the balance disruption are the size and configuration of the BOS, the location of the COG in reference to the limits of stability (LOS) (41), speed of postural movement (39), muscle strength and past experiences (41). Where the threat on balance is minimal or when trying to minimize postural sway during quiet standing, healthy individuals use the ankle strategy which involves activation of the ankle muscles (39). In more perturbed situations, where the body's centre of mass (COM) exceeds a particular distance (i.e. when the COG is located near the LOS perimeter) or the velocity is too great for the ankle strategy to be successful in maintaining balance, a transition occurs to the hip strategy (41). This involves extending or flexing at the hip joint in order to move the COM in an anterior or posterior direction (1, 41). Unlike the above two strategies which correct equilibrium by repositioning the COG back over the fixed BOS, the stepping strategy prevents a fall by placing the BOS under the COG. This strategy is used when the

perturbation or the velocity of displacement is too great for the hip strategy to maintain balance (41). These three strategies are flexible and form a continuum under changing external circumstances that can be adapted depending on the task constraints (39).

2.3 Balance in the game of football

Football is a game where players need excellent standing balance (19) because many skills, such as passing or shooting, are executed from a single leg stance (8, 21). Consequently the stability of the stance foot becomes a crucial element in kicking accurately (21). Therefore, dynamic balance is more important in football compared to sports dominated by performance relying on both legs (18). Furthermore, perturbations from fast moving limbs in change of direction and physical encounters with opposing players all threaten to disrupt a player's balance (20). Research has shown that excellent balance skills are critical in order to kick accurately (22) and perform optimally during speed and agility type drills (36). Moreover, dynamic balance is vital in multi-directional sports, where deceleration is required to strike the ball (42). The ability to decelerate might serve to enhance ball speed which is dependent on the COM deceleration during the last step (43). Due to the physical demands placed on a footballer's postural control system, it is unsurprising that research has observed that football players possess superior dynamic balance to active controls (32) and displayed greater reach distances in the SEBT than their basketball and gymnastics equivalents (8). The authors put this down to the number of unilateral movements that a football player makes in playing the game, with their COM often falling outside their BOS (44) and the possibility of superior joint strength due to the forces they experience during competition (8). Matsuda et al. (27), observed that football players were more stable and displayed less laterality in single leg stances compared to basketball players and swimmers. They observed that by correcting body

sway more frequently, the footballers made better use of their somatosensory system to balance (27). The authors, however, could not conclude whether this superior ability to balance was innate or developed through years of practice (27). Additionally, elite players perform better in static and dynamic single limb stance tests than less skilled players (7, 21, 45). This could be attributed to a more efficient use of proprioceptive and vestibular information with less reliance on vision (21) or a better internal representation of erect posture (45).

In football, it has become imperative that research into specific neuromuscular components such as eccentric strength and power that may be associated with dynamic balance is conducted (8). This can further the design of more specific balance interventions in order to improve performance and minimise injury risk (46). However, the literature has revealed conflicting evidence (28, 30, 32, 33, 35, 47, 48) regarding the relationship between strength and power in balance performance amongst athletes.

2.4 The relationship between power and dynamic balance

Power is defined as the amount of work produced per unit time or the product of work and velocity (14). Power can be utilized across virtually all dynamic muscle actions and shares a strong association with movement from functional daily life activities to elite sports performance (49). The ability of the body's musculature to produce large amounts of power is considered to be a strong predictor of athletic success (14, 15). High-threshold motor units are used minimally during daily activities but are essential for intense athletic competition and for sudden movements that require high levels of muscular power (6). In the ageing population, a lack of power and greater asymmetry seems to be associated with falling and

also appears to be a relevant measure of fall risk (50, 51) suggesting that a loss of balance might require a rapid force generation to bring the COG back within the body's BOS (50, 51). Furthermore, Orr (52) and Woollacott and Tang (53) concluded that improved balance in the elderly was positively related to power training.

However, studies into the relationship between power and balance in athletic populations remain inconclusive. For example three studies found that power and balance were significantly related (28, 29, 47). Erkmen et al. (28) found a significant negative correlation between CMJ height and single leg stance on the non-dominant limb in the balance error scoring system (BESS) ($r = -0.596$, $p = 0.03$). Johnson and Woollacott (29), observed that elite power athletes respond faster to unanticipated balance perturbations than endurance athletes. The difference in time to stabilise the centre of pressure (COP) was significantly faster in the power than the endurance athletes at higher perturbation velocities ($p = 0.02$). This was attributed to faster onset times of muscle-contraction, larger amplitudes of muscle responses and greater force of the plantar flexors in power trained athletes compared to the endurance trained athletes. Furthermore, Gualtieri et al. (47) tested footballers on the Libra fixed point balance test, finding that footballers with greater mono-countermovement jump height demonstrated greater stability on the Libra scale (a tilting platform). In contrast, Muehlbauer et al. (30) found no correlation between the countermovement jump height and dynamic balance in a young adult population group, concluding that the two outcome measures were independent of each other.

There is unequivocal evidence for a relationship between power and dynamic balance in the elderly population where a rapid force generation may prevent a fall. Furthermore, it is likely

that footballers with greater power may perform better in balance tests due rapid force generation in stabilising the body's COM. However, there have been only a few studies that have investigated this relationship and the evidence still remains inconclusive.

2.5 The relationship between eccentric strength and dynamic balance

A lesser studied component of the strength spectrum is eccentric strength (10). An eccentric contraction occurs when the force or torque that a muscle can produce is less than the resistance or load torque, and the activated muscle lengthens as a result to lower the load (6). Eccentric strength would therefore be the maximal amount of force a muscle can resist. Eccentric contractions occur frequently in functional activities and athletic situations (6) and are characterized by high force production (10) compared to concentric contractions. The ability of the muscle to absorb energy during an eccentric contraction is used to reduce the speed of a movement (10) and stabilize forces imposed on the body's centre of mass (54, 55). This possibly protects the less compliant elements of the neuromuscular system from damage due to high impact forces with the net effect of enhancing performance (6).

Research into muscle strength using an eccentric mode of testing is limited (10). Two studies have demonstrated a significant relationship between eccentric strength and functional performance in healthy athletic populations (56, 57). Baldon et al. (57) concluded that greater eccentric hip abductor torque was related to better performance in functional tests; triple long jump for distance and the triple hop for speed, whereas Anderson et al. (56) observed that the eccentric hamstring isokinetic force at 90 degrees per second was correlated to agility time ($r = 0.58$, $p = 0.0001$). Furthermore, Santos et al. (58) demonstrated the positive effects of eccentric training on knee extensor strength and performance in functional hop tests.

However, the relationship between eccentric strength and balance may be less clear.

Guskiewicz (39) stated that muscular weakness, range of motion and proprioceptive deficits may challenge a person to maintain their balance or even cause a loss of balance. However, McCurdy and Langford (46) observed that as long as a minimum threshold of strength can be achieved, the relationship between the strength and balance is minimal. For example, there is a correlation between lack of strength and fall risk been observed in the elderly and osteoporotic populations (59, 60). Nonetheless, strength in the muscle groups surrounding the knee joint may be important for maintaining dynamic balance even in athletic populations (35), possibly due to the increased demands on the musculature that control the COG in more demanding situations.

Numerous studies have investigated eccentric contractions of the knee extensors in dynamic situations (31, 34, 54). Two studies have identified the primary function of the knee extensors was to eccentrically decelerate the downward motion of the body's COM after impact during functional movements (54) and absorb mechanical energy during the support phase of balance recoveries (55). Additionally, two electromyography (EMG) studies have confirmed high activation levels of the knee extensor group during the lowering phase of the SEBT (31, 34). This was attributed to these muscle groups eccentrically contracting to control the increasing knee flexion moment during the reaching movement (31). The limitation of these studies is that EMG activity does not quantify the amount of torque produced by these muscles. Therefore it is difficult to ascertain if there is a relationship between eccentric strength and dynamic balance.

Investigations into the relationship between strength and dynamic balance, have done so using the concentric mode of contraction, with most finding no significant correlations (30, 32, 33, 46). Muelbauer et al. (30) measured dynamic balance using an oscillating platform that delivered unexpected perturbations as well as isometric strength of the plantar flexors. No statistically significant correlations were found between strength and balance (30). McCurdy and Langford (46) tested the relationship between single leg dynamic balance using a wobble board with unilateral squat strength (1RM) and found no significant correlations in their sample of student men and women. Thorpe and Ebersole (32) assessed balance using the SEBT and concentric strength of the knee extensors and flexors at 60 degrees per second in female non-football and football participants. They did not find any significant correlations between the three reach distances recorded (anterior, medial and posterior) and concentric strength in both sample groups. Similarly, Paterno et al. (33), found no significant correlation between concentric strength at 180 degrees per second and performance in the YBT in 34 male and female young athletes. In contrast, Hesari et al. (48) found positive relationships between excursion distance in the SEBT and hip muscle strength determined by manual muscle testing. Most recently, one study looked at eccentric strength and dynamic balance with significant findings (35). Lockie et al. (35) found stronger left knee extensor strength in both concentric (60, 180 and 240 degrees per second) and eccentric (30 degrees per second) modes was associated with better performance in the SEBT in young, male team-sport athletes. However, it is difficult to draw definite conclusions from this study based on the small sample size ($n=16$). The SEBT being a two-phase task may result in eccentric strength possessing a stronger relationship with performance in SEBT than concentric strength (32), possibly due to the greater mechanical efficiency and energy dissipation that can be achieved with eccentric contractions compared with concentric contractions (6). Lastly, Tsang et al. (61) highlighted the importance of eccentric strength in dynamic balance activities.

Observations were made that Tai Chi practitioners demonstrated higher relative knee extensor and flexor muscle strength in eccentric contractions compared with controls. Although static balance tests demonstrated no difference in sway angles between groups, less body sway in the Tai Chi group was observed in the perturbed single leg stance test.

2.6 Summary

There is evidence for the need for superior balance in football, enabling players with better balance to have a decreased risk of injury and a potential improvement in performance. There has been little analysis of the relationship between lower extremity eccentric strength and power with dynamic balance in healthy athletes (35). Dynamic balance is an area that has a need for this capacity to be trained and research into these relationships will help to inform training programmes or prevent injuries.(35).

CHAPTER THREE

3. METHODS

3.1 Study design

The relationships between eccentric strength and power with dynamic balance were examined using a cross-sectional, observational design on a university football team and retrospectively on a professional football team. To determine these relationships, dynamic balance using the Y-balance test (YBT) on both the dominant and non-dominant legs was assessed owing to single leg stances being task specific in balance testing of football players (21). Furthermore, due to both knee and hip strategies being used to maintain balance and stability in dynamic activities (17), isokinetic eccentric testing of the knee extensors and flexors, as well as the countermovement jump to assess lower extremity strength and power, were selected.

3.2 Participants

A convenience sample of fifty-five healthy male football players volunteered to participate in this study. This comprised of a 91 percent participation rate in each team that was recruited (figure 1). Testing procedures were explained and an information sheet (appendix B) was provided. However, data analysis was performed on 50 participants, after three data sets were withdrawn due to high isokinetic coefficient of variance (CV) values and two participants self-reported injuries (figure 1). The 50 participants were further split into two groups based on playing level, 27 participants were from the same university senior first team squad and 23 were from a professional football club competing in the South African Football Association (SAFA) second division (or Vodacom League) (see table 2 for each groups physical characteristics). Leg dominance was established by asking the participant which leg he

preferred using to kick the ball. The university group were actively engaged in football activity which involved at least two training sessions per week and one match played on the weekend. The professional group were actively engaged in football activities twice daily, six days per week, which included two matches per week. The investigation was initially approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M120707) for research into university footballers (appendix C). The anonymous retrospective analysis was performed on the team of professionals only after ethics amendment (appendix D). Before testing, all participants completed a self-reported medical screening questionnaire (appendix E) and signed a written informed consent (appendix F and G).

3.2.1 Participant inclusion criteria

Male football players over the age of 18 years old playing for either a university senior first team or professional football in the SAFA Second Division (or the Vodacom League) were included.

3.2.2 Participant exclusion criteria

Participants were excluded if they reported the presence of any lower limb injury within the last six months, a current upper respiratory tract infection, any bone or joint abnormalities, any uncorrected visual or vestibular problems and/or a concussion within the last three months.

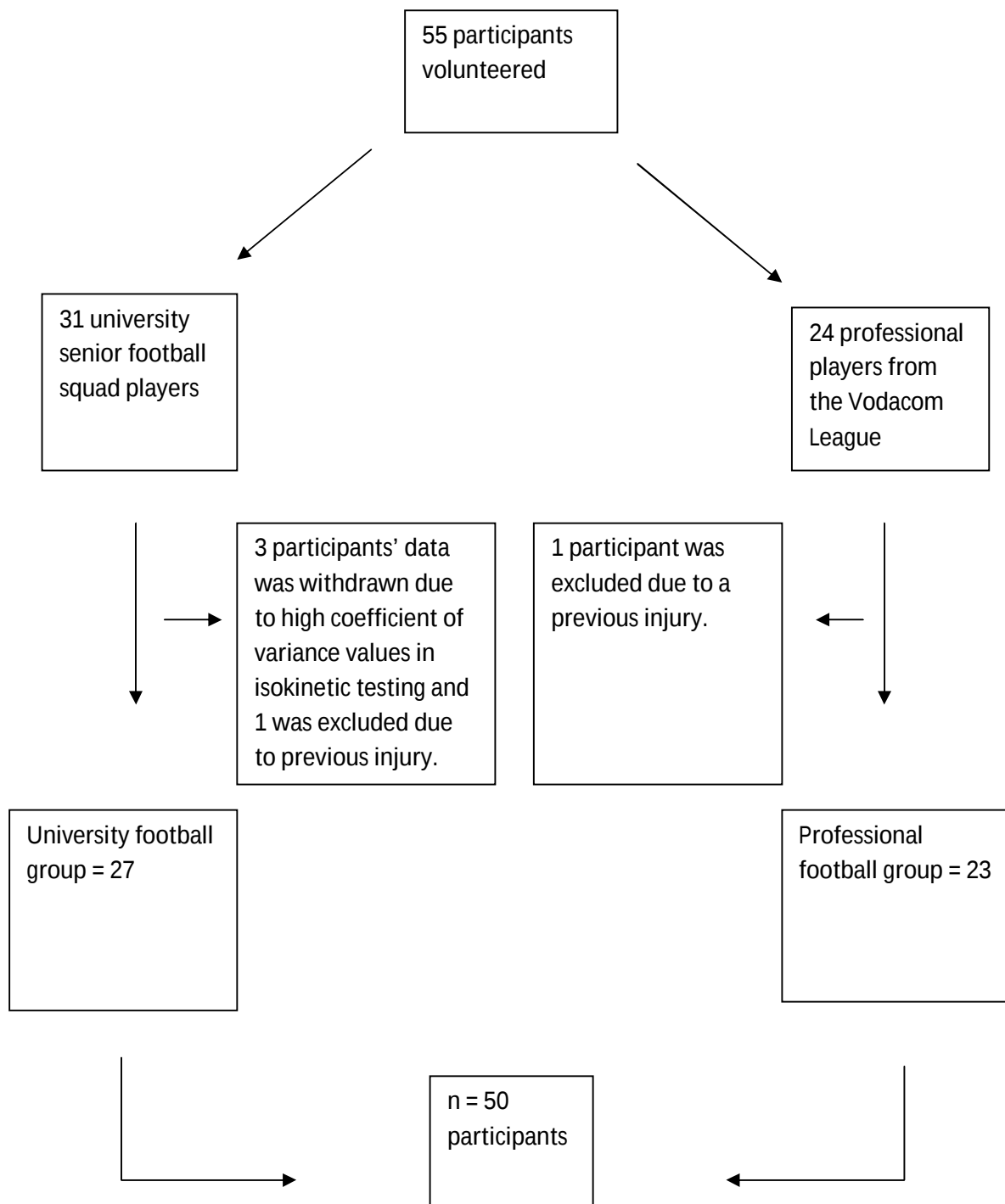


Figure 1: Flow chart depicting the data collection process

3.3 Procedures and instrumentation:

All individual participant data were collected on a single pre-arranged data collection day. A strict testing order was maintained with a 20 minute rest period between tests to ensure that neuromuscular fatigue was kept to a minimum. The test sequence began with dynamic balance followed by power and then strength testing.

The following extraneous factors that affect balance were kept to a minimum;

1. To minimize fatigue, participants were asked to refrain from exercising on the test day (62),
2. Participants performed all tests barefoot, as footwear affects balance performance (63),
3. All participants were tested at approximately the same time of day (which was the afternoon) to eliminate diurnal variations in postural control (64).

Prior to testing, participants were given an eight minute standardised warm-up routine which included light jogging and simple dynamic stretches which were specifically targeted at the muscles of the knee and hip joints. Each test protocol and participant requirements were explained and demonstrated prior to commencement.

3.3.1 Anthropometric measurements:

Anthropometric measurements were carried out before testing commenced. Body mass was measured using an electronic scale (Seca, Medical Scales and Measuring Systems, Birmingham, United Kingdom), and height was measured using a stadiometer (Seca). Leg lengths were measured using a standard tape measure (Seca) with the participant lying in the supine position on a plinth. Both legs were straightened to equalise the pelvis. The

measurement was taken from the anterior superior iliac spine, to the centre of the medial malleolus of the ipsilateral leg (9).

3.3.2 Dynamic balance

Dynamic balance was measured using the YBT (Y-Balance Test[™], Move2Perform, Evanville, IN), an instrumented version of the SEBT. The testing device for the YBT has been fully described in the literature (65). After more than a decade of research, the SEBT is considered a valid test of dynamic balance in physically active individuals (66). Furthermore, the instrumented version of the YBT has a ICC (inter-correlation coefficient) for composite reach score of 0.91 for intrarater and 0.99 for interrater reliability (65), and has been used to predict lower extremity injuries in athletes (23, 25, 26). Similar to the SEBT, the YBT, requires the participant to maintain a unilateral stance, while reaching maximally with the contra lateral limb in a specified direction without compromising the BOS of the stance leg (9, 67). The further the distance reached by the participant, the greater the challenge to the neuromuscular and balance control systems (31, 32, 34). The YBT incorporates three directions, namely the anterior, posterior medial and the posterior lateral directions (see figures 2-4), opposed to the eight directions used with the SEBT. Due to the SEBT being arguably more redundant due to the similarity in lower extremity function in many of the eight directions (68, 69), the reduction in reach directions streamlines the administrative aspect of the YBT, without diminishing its functional-assessment value (68).

All performances in the YBT were monitored and recorded by one experienced tester. To rule out any learning effects, the participant performed the YBT with four practice trials in each direction on both legs prior to testing (70). The participant then rested for a further three minutes prior to the start of the test. A standard test procedure was followed in order to

improve reliability and consistency of performance (65). The order of testing was as follows; three trials standing on the right foot reaching in the anterior direction followed by three trials on the left foot in the same direction. This procedure was repeated for the post medial direction and lastly, the post lateral direction (65). Before the start of the trial, the participant had to position the most distal aspect of his stance foot at the centre of the platform on the anterior red line. His reach foot was placed between the stance platform and the adjacent posterior pipe of the YBT device. The participant was then instructed to make a maximal reach by pushing the reach indicator as far as possible in the specified direction with the most distal aspect of the free limb. During the reaching movement, the participant was required to maintain the stance foot in its original position, with hands on the hips and the stance heel in contact with the platform (32, 69, 70). Once maximal reach distance was achieved, participants had to return the reach foot to the designated starting area under control (32). During the YBT, participants were instructed to move in any way possible to achieve a maximum reach distance (67). A trial was discarded and repeated if the participant;

1. Failed to maintain a unilateral stance on the stance platform and touched the floor outside the starting zone with the reach foot (65),
2. Placed his toes on top of the reach indicator for support (65),
3. Did not return his reach foot to the designated starting area under control (65),
4. Failed to maintain the reach foot in contact with reach indicator on the red target area while it was in motion (65), and
5. Lifted the stance leg heel off the platform or removed hands from the hips (32, 69, 70).

To reduce the effects of fatigue on performance in the test, a 15 second rest period after each trial (34) and a three minute rest between each direction was given to each participant (34).

Performance was quantified by recording the maximal reach distance (measured on the side of the reach indicator where the most distal part of the foot reached) (65).



Figure 2: Anterior reach direction on the left leg performed by the researcher

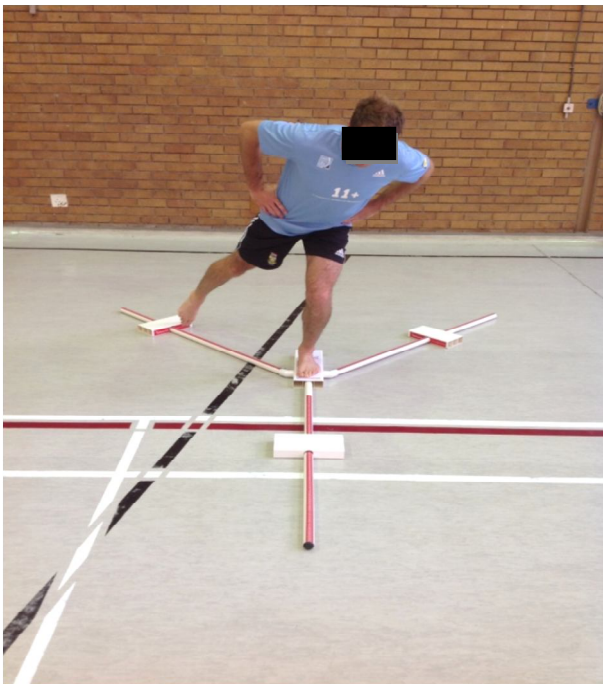


Figure 3: Post medial reach direction on the left leg performed by the researcher

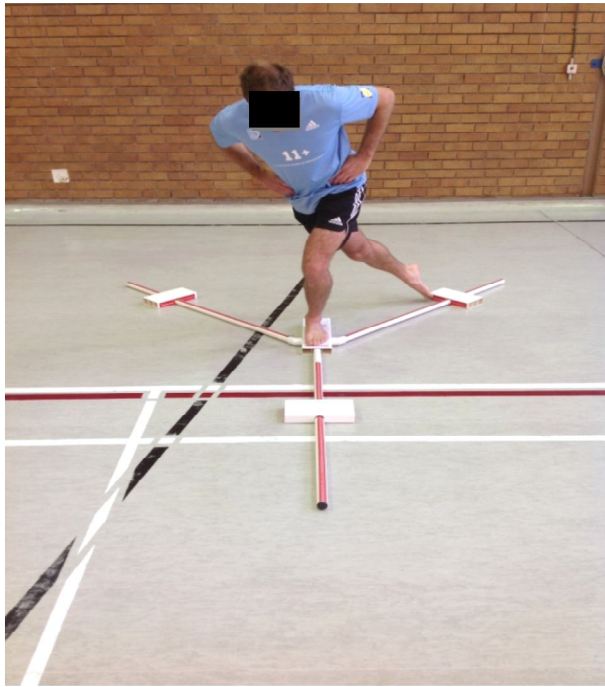


Figure 4: Post lateral reach direction on the left leg performed by the researcher

3.3.3 Counter Movement Jump (CMJ):

The CMJ is a non-invasive and valid method of assessing jumping ability and explosive power of the lower extremity (71-73) and has been used extensively in football as a performance measure (20, 74). Vertical jump displacement was measured electronically using the Fusion Sport Smart Jump mat (Fusion Sport, 2 Henley ST, Coopers Plains, QLD, 4108, Australia). The Smart Jump PDA (HP IPAQ 112, Hewlett Packard Company, Palo Alto, CA 94304) which works in conjunction with the Fusion Sport Smart Jump mat, digitally registered the maximal vertical jump displacement reached, to the nearest millimetre. Flight time-based measurements on contact mats are considered to be the most reliable and valid of all field tests for measuring height in vertical jump testing with an ICC value of 0.98 (71).

At the start of each trial, the participant stood barefoot and motionless at the centre of the contact mat. The participant then made a quick countermovement, flexing at the hips, knees and ankles and then took a jump for maximal vertical height. The descent to take-off was in one consecutive movement with no pause in between. The depth of knee flexion was individually determined by the participant (75). In order to avoid immeasurable work output; the participant had to perform the jump with minimal horizontal and lateral displacement and was not allowed to bend the knees when in the air (71, 76). In order to eliminate coordination of the upper and lower limbs as a confounding variable in the assessment of the lower limb power, participants were asked to keep their hands on their hips throughout performance of the CMJ (77). The participant then took a two minute standing rest before taking his next jump (77). Each participant performed three maximal trials (77). The jump with the highest value (cm) was selected.

3.3.4 Eccentric strength testing

Eccentric strength testing was performed on an isokinetic dynamometer (Biodex System 3, Biodex Medical System, INC, 20 Ramsay Road, Shirley, NY, 11967, USA) to determine the eccentric peak torque of the knee flexors and extensors at an angular velocity of 90 degrees per second ($^{\circ}/s$). The primary advantage of the isokinetic dynamometer in quantifying knee extensor and flexor strength is that the device provides variable resistance at a constant speed, so that the muscle groups may be exercised to their maximum potential throughout the knee joint's full range of motion (ROM) (78). Isokinetic testing is a reliable means of measuring muscle strength with ICC values of 0.90 and 0.92 for eccentric contractions at low speeds in extension and flexion, respectively (79). Furthermore, the validity and reliability of the Biodex 3 to produce valid and reliable measures of torque, velocity and position have been demonstrated (80).

Procedures for isokinetic assessment of the knee joint followed the protocol as set out by Perrin (78). After the dynamometer was calibrated, the rotational axis of the dynamometer was visually aligned with the lateral femoral condyle of the knee being tested. The participant was then secured in a seated position with the hip angle at 90 degrees with the body maximally strapped and arms crossed at the chest (78). The ROM at the knee joint that was comfortable for the athlete was set for both extension and flexion and approximated 80 degrees at the knee joint in both groups. Gravity correction was done by weighing the limb at 30 degrees of extension. A standardised verbal explanation of the concept of isokinetic eccentric testing was given to each of the participants and consistent verbal encouragement was used by the same researcher to ensure maximal effort was given during maximal trials (78). Four practice trials were performed at 25, 50, 75 and 100 percent of maximal effort, respectively. On completion of the practice trials, the participant rested for 90 seconds prior to the maximal eccentric trials. Two sets consisting of five continuous repetitions were performed at 90 degrees per second with the starting leg always being the right. A rest period of 90 seconds was given between sets. The set with the highest peak torque to body weight (PT/BW) values with a CV of less than 15% was selected for further analysis.

3.4 Data analysis

The reach distances (cm) for the three directions of the YBT were averaged over the three trials (appendix H). For each leg, the average reach distance (cm) of the three directions was summed and divided by three times the participant's leg length and then multiplied by a 100 to get a normalised reach distance (%) (9, 65). A composite score (or overall normalised reach distance) for the YBT (YBT%) was calculated by averaging the normalised reach

distances of both the dominant (YBT-DL%) and non-dominant legs (YBT-NDL%). PT/BW values were automatically calculated by the Biodex 3 for each leg in both flexion and extension to give a percentage of body weight. A mean for both legs was then calculated by averaging the PT/BW values of the dominant leg (DL) and the non-dominant leg (NDL) $(DL + NDL/2)$. The maximal countermovement jump height (CMJ_H) of the three trials was recorded as the outcome variable for power and reported in centimetres (cm). Statistica, Version 12.0 (Series 0313b, StatSoft) was used for analyses. All numerical values were expressed as medians and interquartile ranges (IQR) as the data was not normally distributed. Any significant bilateral deficits in performance variables were identified using the Wilcoxon Matched Pairs Test. The Mann-Whitney U Test was applied to calculate significant between-group differences in the performance and physical measurements. Spearman rank correlation coefficients were used to determine the relationships between isokinetic PT/BW values of the knee extensors/flexors and CMJ height (CMJ_H) with normalised reach distances in the YBT. The significance level was set at a level of $p < 0.05$.

CHAPTER FOUR

4. RESULTS

4.1 Physical characteristics of the participants:

The results of the complete group of players of this study are displayed in table 1. They can be classified as young adults with a normal body mass index and have been playing football for at least 12 years.

Table 1: Physical characteristics of the study participants

	Participants n = 50 Median (IQR)
Age (years)	22 (20-23)
Playing experience (years)	12 (11-14)
Mass (kg)	65.1 (60.5-69.4)
Height (m)	1.71 (1.67-1.74)
BMI (kg/m²)	22.4 (21.3-23.5)
Leg length (cm)	90.4 (87.5-92.5)
BMI = Body mass index	

Comparisons of the physical characteristics and playing experience between the two groups are presented in table 2. No significant differences between the groups for body mass, height and body mass index (BMI) were observed. However, the professional group was significantly older ($p = 0.008$) and more experienced with greater playing experience ($p = 0.0005$) than the university group.

Table 2: Physical characteristics of the university and professional groups

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR) (p value)
Age (years)	21 (19-22)	22 (21-24)* (p = 0.008)
Playing experience (years)	11 (10-12)	14 (12-15)* (p = 0.0005)
Mass (kg)	63.7 (59.9-68.1)	66.6 (61.4-69.5)
Height (m)	1.71 (1.66-1.74)	1.72 (1.67-1.74)
BMI (kg/m²)	21.7 (21.2-23.8)	22.7 (21.7-23.3)
Leg length (cm)	91 (87.5-93)	90 (86.8-92.5)
BMI = Body mass index * significant compared to the university group		

4.2 The performance characteristics of the university and professional groups

4.2.1 Dynamic balance

No significant differences were observed between the university and professional groups for YBT score and normalised reach distances on either leg (Table 3). Furthermore, bilateral balance deficits within each group were not significant (Table 3).

Table 3: Dynamic balance characteristics of the participants

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
YBT (%)	89.3 (84.3-92.1)	90.8 (87.3-94.3)
YBT-DL (%)	89.3 (85-93.2)	90.8 (86.9-94.3)
YBT-NDL (%)	89.8 (82-92.9)	92.2 (87.7-95.4)
YBT% = composite reach score in the YBT; YBT-DL% = normalized reach distance on the dominant leg in the YBT; YBT-NDL% = normalised reach distance on the non-dominant leg in the YBT		

4.2.2 Eccentric strength of the knee extensors

No significant differences in PT/BW values in eccentric testing of the knee extensors were found between the two groups. Additionally, no significant bilateral strength deficits were observed in either group (Table 4).

Table 4: Eccentric strength (PT/BW) of the knee extensors of the participants

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
Mean (%)	384 (310-407)	390 (364-446)
DL (%)	363 (319-446)	401 (374-459)
NDL (%)	361 (303-409)	394 (342-425)
DL = dominant leg; NDL = non-dominant leg, Mean = average PT/BW of the two legs		

4.2.3 Eccentric strength of the knee flexors

No significant differences for PT/BW were found between the two groups. However, significant bilateral deficits for the knee flexors were detected, where the dominant leg in both groups was significantly stronger (university group; $p = 0.0008$ and professional group; $p = 0.01$) than the non-dominant leg (Table 5).

Table 5: Eccentric strength (PT/BW) of the knee flexors of the participants

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
Mean (%)	236 (210-288)	255 (220-276)
DL (%)	259 (224-297)	274 (231-295)
NDL (%)	222(186-275)	236 (225-268)
DL = dominant leg; NDL = non-dominant, Mean = average PT/BW of the two legs		
*DL significant significantly greater than the NDL		

4.2.4 Power

No significant differences were found in CMJ height between the two groups (Table 6).

Table 6: Countermovement jump height of the participants

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
CMJH (cm)	38.3 (34.8-42)	35.9 (33.5-38.5)
CMJH = countermovement jump height		

4.3 Relationships between eccentric strength of the knee extensors and dynamic balance

4.3.1 University group

Significant positive correlations were found between mean eccentric PT/BW of the knee extensors and YBT% ($r = 0.42$, $p = 0.03$) (figure 5 and table 7) and between eccentric PT/BW of the non-dominant leg knee extensors and YBT-NDL% ($r = 0.50$, $p = 0.008$) (figure 6 and table 9). A non-significant correlation was found between eccentric PT/BW of the dominant leg knee extensors and YBT-DL% ($r = 0.33$, $p = 0.1$) (table 8).

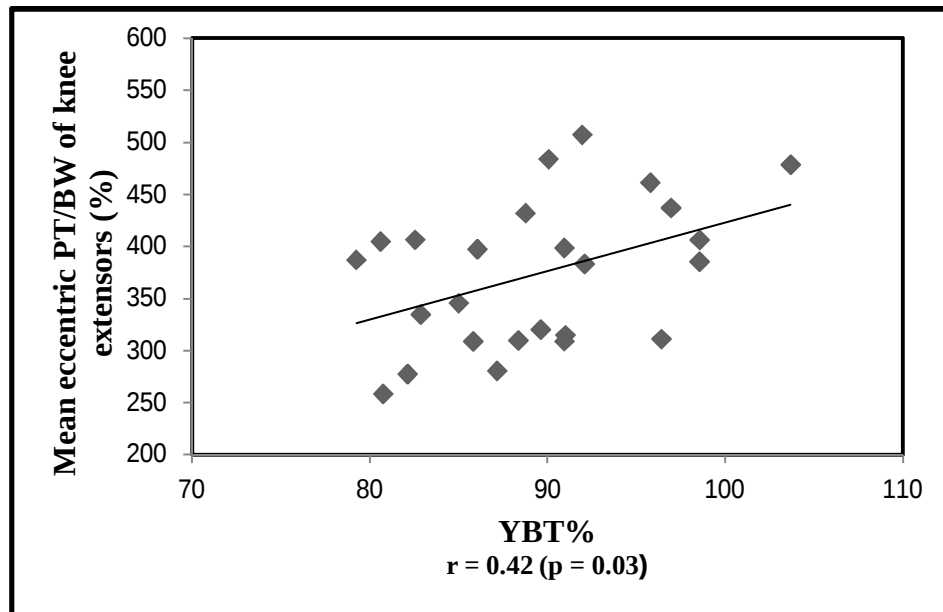


Figure 5: The relationship between mean eccentric strength of the knee extensors with composite reach score (YBT%) in the university group.

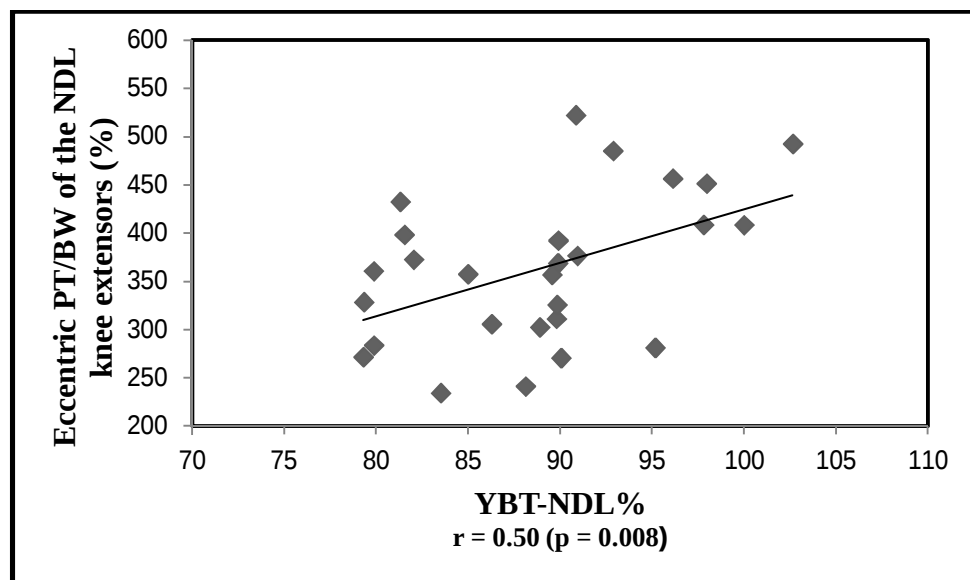


Figure 6: The relationship between eccentric strength of the non-dominant limb (NDL) knee extensors with normalised reach distance on the non-dominant limb (YBT-NDL%) in the university group.

4.3.2 Professional group

In the professional group, non-significant negative correlations were found between mean eccentric PT/BW of the knee extensors and YBT% ($r = -0.08$, $p = 0.72$) (table 7) and between eccentric PT/BW of the non-dominant leg knee extensors and YBT-NDL% ($r = -0.1$, $p = 0.65$) (table 9). A non-statistically significant positive correlation was found between eccentric PT/BW of the dominant leg knee extensors and YBT-DL% ($r = 0.06$, $p = 0.79$) (table 8).

4.4 Relationships between eccentric strength of the knee flexors and dynamic balance

4.4.1 University group

Non-statistically significant positive correlations were found between mean eccentric PT/BW of the knee flexors and YBT% ($r = 0.17$, $p = 0.39$) (table 7). Furthermore, eccentric PT/BW of the dominant and non-dominant leg knee flexors yielded non-significant correlations with YBT-DL% ($r = 0.15$, $p = 0.46$) and YBT-NDL% ($r = 0.24$, $p = 0.22$), respectively (tables 8 and 9).

4.4.2 Professional group

A non-significant negative correlation was found between mean eccentric PT/BW of the knee flexors and YBT% ($r = -0.27$, $p = 0.21$) (table 7). Non-significant negative correlations were also found between eccentric PT/BW of the dominant and non-dominant leg knee flexors with YBT-DL% ($r = -0.28$, $p = 0.19$) and YBT-NDL% ($r = -0.15$, $p = 0.49$), respectively (tables 8 and 9).

4.5 Relationships between power and dynamic balance

4.5.1 University group

Significant positive correlations were found between CMJ_H and YBT-NDL% ($r = 0.40$, $p = 0.05$) (table 9 and figure 7). Non-significant correlations were found between CMJ_H and YBT% ($r = 0.36$, $p = 0.07$) and YBT-DL% ($r = 0.35$, $p = 0.08$), respectively (tables 7 and 8).

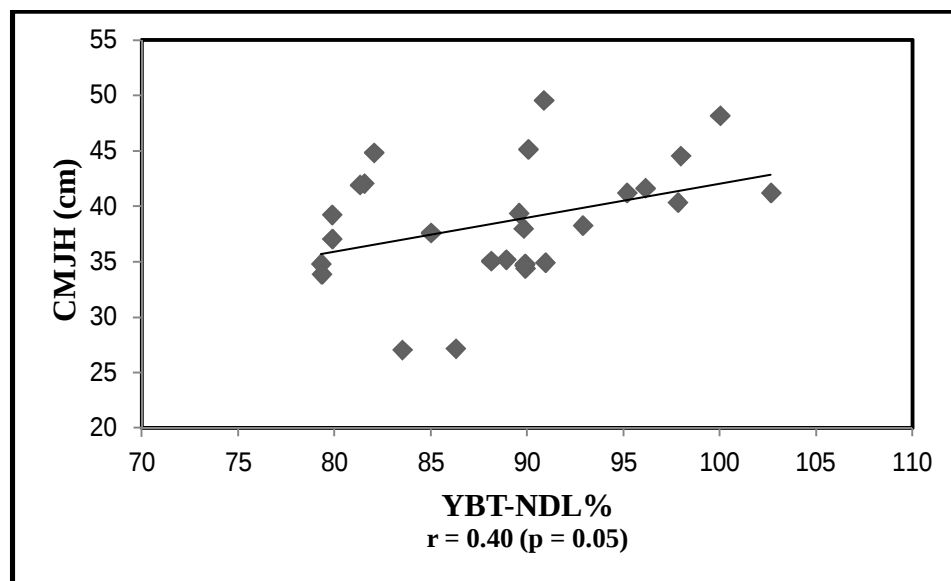


Figure 7: The relationship between power with normalised reach distance on the non-dominant limb (YBT-NDL%) in the university group

4.5.2 Professional group

Significant correlations were found between CMJ_H and YBT% ($r = 0.52$, $p = 0.02$) (table 7 and figure 8) and YBT-NDL% ($r = 0.56$, $p = 0.006$) (table 9 and figure 9), respectively. A non-significant correlation was found between CMJ_H and YBT-DL% ($r = 0.36$, $p = 0.1$) (table 8).

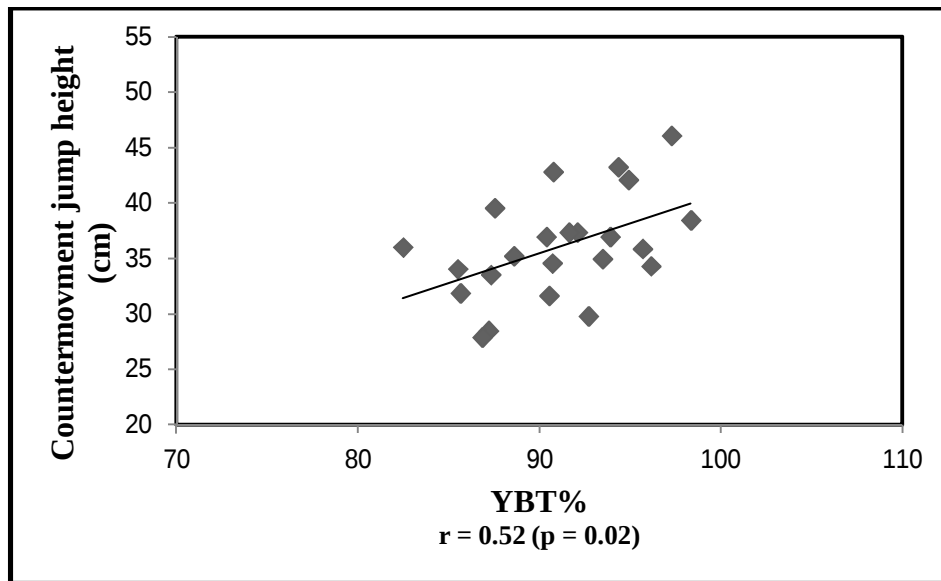


Figure 8: The relationship between power with composite reach score (YBT%) in the professional group

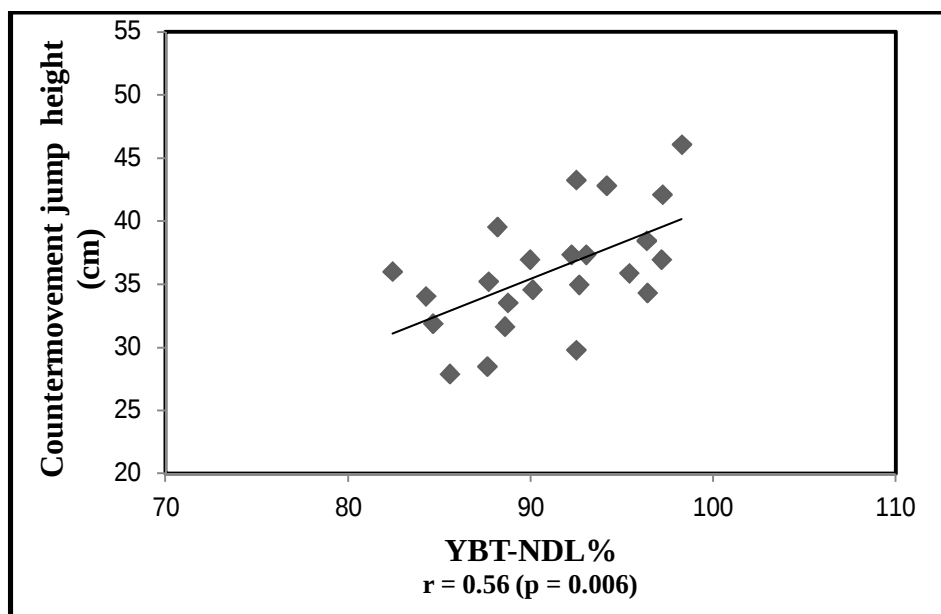


Figure 9: The relationship between power with normalised reach distance on the non-dominant limb (YBT-NDL%) in the professional group.

4.6. Summary of correlations

Table 7: Summary of correlations between power and mean eccentric strength with composite score (YBT%):

	University n = 27 r (p-value)	Professional n = 23 r (p-value)
	YBT%	YBT%
KE	0.42 (0.03)*	-0.08 (0.72)
KF	0.17 (0.39)	-0.27 (0.21)
CMJH	0.36 (0.07)	0.52 (0.02)*
YBT% = Composite reach score in the YBT; KE = Mean eccentric PT/BW of knee extensors; KF = Mean eccentric PT/BW of knee flexors; CMJH = countermovement jump height *Significant at $p < 0.05$		

Table 8: Summary of correlations between power and dominant leg eccentric strength with normalised reach on the dominant leg (YBT-DL%):

	University n = 27 r (p-value)	Professional n = 23 r (p-value)
	YBT-DL%	YBT-DL%
KE-DL	0.33 (0.1)	0.06 (0.79)
KF-DL	0.15 (0.46)	-0.28 (0.19)
CMJH	0.35 (0.08)	0.36 (0.1)
YBT-DL% = Normalised reach in the YBT on the dominant leg; KE-DL = Eccentric PT/BW of the dominant leg knee extensors; KF-DL = Eccentric PT/BW of the dominant leg knee flexors; CMJH = countermovement jump height		

Table 9: Summary of correlations between power and non-dominant leg eccentric strength with normalised reach on the non-dominant leg (YBT-NDL %):

	University n = 27 r (p-value)	Professional n = 23 r (p-value)
	YBT-NDL %	YBT-NDL %
KE-NDL	0.50 (0.008)*	-0.1 (0.65)
KF-NDL	0.24 (0.22)	-0.15 (0.49)
CMJH	0.4 (0.05)*	0.56 (0.006)*
YBT-NDL% = Normalised reach in the YBT on the non-dominant leg; KE-NDL = Eccentric PT/BW of the non-dominant leg knee extensors; KF-NDL = Eccentric PT/BW of the non-dominant leg knee flexors; CMJH = countermovement jump height *Significant at $p < 0.05$		

4.7 Coefficient of variance for isokinetic testing

The coefficient of variance values can be viewed in tables 10 and 11. The values for both the university and professional groups fall within the accepted norm of 15% for isokinetic testing.

Table 10: Coefficient of variance for isokinetic testing of the knee flexor muscle group

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
DL	10.2 (7.8-12.2)	8.7 (6.6-12.3)
NDL	9.3 (5.3-13.7)	10.5 (6-12.3)
Values expressed as a percentage DL = dominant leg; NDL = non dominant leg		

Table 11: Coefficient of variance for isokinetic testing of the knee extensor muscle group

	University n = 27 Median (IQR)	Professional n = 23 Median (IQR)
DL	7.2 (4.8-10.2)	7 (3.6-8.7)
NDL	6.5 (4.9-11)	7.8 (5.8-11.3)
Values expressed as a percentage DL = dominant leg; NDL = non dominant leg		

CHAPTER FIVE

5. DISCUSSION

5.1 Introduction

The relationship between strength, power and dynamic balance in young male football players remain unresolved. Results from previous studies investigating the relationship between strength, power and dynamic balance are conflicting (28, 30, 32, 33, 35, 47, 48). There is evidence for the need for superior balance in football, enabling players with better balance to have a decreased risk of injury and a potential improvement in performance. For that reason, the aim of this study was to investigate the relationship between eccentric strength and power of the lower extremity with dynamic balance in male football players.

The results confirm that there was a moderate relationship between mean eccentric strength of the knee extensors with composite reach performance in the university group. However, eccentric strength of the non-dominant leg knee extensors demonstrated a significant and stronger relationship with ipsilateral dynamic balance compared to the relationship between similar variables on the dominant leg. In the professional group, a relationship existed between CMJ_H and composite reach performance. In both the university and professional groups, a significant positive relationship was observed between CMJ_H and reach performance on the non-dominant leg. Surprisingly, no significant relationships were observed between eccentric strength values and power with dynamic balance on the dominant leg in either group. Furthermore, no significant relationship existed between eccentric strength of the knee flexors and reach performance in both groups.

5.2 Eccentric strength of the knee extensors and dynamic balance

The results show that in the university group, mean eccentric strength of the knee extensors had a significant relationship with composite reach performance. Further analysis revealed that a significant relationship existed between eccentric strength of the non-dominant leg knee extensors and non-dominant leg reach performance. This suggests that participants were more reliant on eccentric strength of the knee extensors to maximize their balance performance on their non-dominant leg. These findings support those of Lockie et al. (35), who divided their sample of male team sport athletes into two groups by composite score in the SEBT. The author found that the better performing group had significantly greater reach distance (%) compared to the lesser performing group, when the left leg was used for stance compared to that of the right. Furthermore, the eccentric strength (at 30 degrees per second) of the left knee extensors was significantly greater in the group with the better balance. However eccentric strength on the right leg showed no significant differences between groups. In addition, Santos et al. (58) observed that eccentric training not only improves knee extensor eccentric peak torque, but also performance in functional hop tests, confirming the importance of eccentric strength during weight-bearing activities. Alternatively, Thorpe and Ebersole (32), did not observe any significant correlations between reach distance in the SEBT and concentric at 60 degrees per second in knee extension in female football and non-football athletes. Similarly, Paterno et al. (33) found no significant relationship between knee extensor concentric strength at 180 degrees per second and dominant leg performance in the YBT, in male and female young athletes. The excursions of the YBT are a challenge to an athlete's balance control system (68), mostly due to the greater proportion of the reach leg's mass extending to the outer perimeter of the LOS. Therefore, the further the participant reaches, the less stable he becomes and the more he needs to compensate with balance strategies to maintain the COG within the very narrow BOS. These strategies demand

strength in the musculature that coordinate the compensatory movements (31). Support for this can be found in a study by Norris and Trudelle-Jackson (34) who observed an increase in activation of the vastus medialis as it eccentrically lengthens during the lowering phase of the YBT. This eccentric lengthening helps control the increasing knee flexion moment as the participant maximally reaches (31). Importantly, knee flexion accounts for 36-51% of the variance in reach distance in the three directions of the YBT (69), which could partly explain the moderate correlation value between mean eccentric strength of the knee extensors and composite reach performance that was observed in the university group. Furthermore, eccentric strength of the knee extensors is an important component during high intensity football actions such as agility, sprinting or dynamic kicking. Similar to the YBT, these situations are characterized by the player's COG moving towards the outer edge of their narrow BOS and sometimes beyond (81), thus challenging their LOS. Therefore it is probable that university football players who have more pronounced eccentric strength to body weight ratio in the knee extensor muscle group may be more capable of executing the appropriate strategy to control the COG in unilateral stances, especially when balancing on the non-dominant leg.

In contrast, the professional group showed a weak, non-significant negative correlation between eccentric strength of the knee extensors and reach performance on both their dominant and non-dominant legs. These findings mirror those of Thorpe and Ebersole (32), who also found a negative correlation between concentric strength of the knee extensors and YBT in female National Collegiate Athletic Association (NCAA) Division 1 football players, but a positive correlation in non-football active controls. Although eccentric muscle activation of the vastus medialis is fairly high in the lowering portion of the YBT (34), the hypothesis that there would be a significant relationship between eccentric strength of the

knee extensors and reach performance was not observed in the professional group. There are two plausible reasons that may explain these findings.

Firstly, it could be argued that isolated single joint strength testing, within this group of highly trained footballers, is not movement-specific enough in order to find a significant correlation with performance in close chain, functional testing (82, 83). Requena et al. (83), using a sample of semi-professional footballers, observed no significant relationships between concentric strength testing at 60 degrees per second with sprint and vertical jump performance. However, in the same study, significant correlations were observed between strength using 1RM half squats as an outcome measure with CMJ height and 15m sprint times (83). Highly complex tasks make up the game of football and it is conceivable that more skilled players, like our professional group, have better coordination and more efficient control over the lower extremity joints in functional movements than amateur players. In players of less skill, isolated muscle strength may still be predictive of performance in dynamic tasks. This may be due to comparatively less synchronised movement and possibly more reliance on a single muscle group to complete tasks like the YBT. Testing within more elite footballers may need to consider this coordinative aspect when strength testing in order to correlate with dynamic performance measures. Therefore it is possible that the insignificant correlation between eccentric strength of the knee extensors and reach performance within the professional group are due to single-joint isokinetic testing being a poor predictor of performance in more complex movements (83).

Secondly, different kinematic strategies adopted by the professionals in the YBT might have resulted in a greater reliance on their hip extensors. Greater flexion at the hip joint due to a more pronounced forward trunk lean, causes anterior displacement of the participants' COM

during the reach which can result in less activation of the knee extensors due to the reduction in the knee flexion moment (5). If this is correct, then the professionals would be more reliant on the strength of their hip extensors to control the hip joint torques during reach performance in the YBT.

5.3 Eccentric strength of the knee flexors and dynamic balance

The results of this study support previous findings that a relationship does not exist between eccentric strength of the knee flexors and dynamic balance. These findings were similar to Lockie et al. (35), who found no significant differences in eccentric knee flexor strength between performance levels in the SEBT. The hypothesis that sufficient knee flexor (in particular the hamstrings) strength would be needed to assist in stabilising the knee during reach excursions was not supported by our results. Observations of relatively low activation levels of the hamstring muscle group during the weight-bearing activities can be found in the literature (31, 84, 85), which reflect their function as a knee joint stabilizer (85) and therefore are less dependent on strength to achieve their purpose (34). This can further explain why the significant difference between eccentric strength of the dominant and non-dominant legs knee flexors observed in both sample groups did not affect performance in the YBT.

In hindsight, the increase in activation levels of the hamstrings during the posterior directions of the YBT (31) can be attributed to the bi-articular nature of this muscle group. Therefore the hamstring's performance as a hip extensor, would infer some degree of strength as it counters the hip flexion moment during maximal reaching (31).

5.4 Power and dynamic balance

Lower extremity power had a significant positive relationship with composite reach performance in the professional group only. However, power had a significant relationship with reach performance on the non-dominant leg in both groups. This demonstrates the importance of power needed in the stance leg within football players to balance. Support for our findings can be observed in the work of Erkmen et al. (28), who observed a moderate negative correlation ($r = -0.59$, $p < 0.05$) between single leg balance performance on the non-dominant leg (in the balance error scoring system) with CMJ height. Therefore, participants who jumped higher also made less balance errors on their non-dominant leg. Additionally, Gualtieri et al. (47) observed a moderate negative correlation ($r = -0.48$, $p < 0.01$) between the mono-countermovement jump height and stability on the Libra platform, with greater stability leading to less deflection of the tilting platform. In contrast, Muehlbauer et al. (30) investigated single leg dynamic balance using unexpected perturbations and CMJ height and concluded that there were no significant correlations between the two variables. However, balance was tested on the dominant leg only, making it difficult to draw appropriate comparisons with the findings in this study. Furthermore, it is possible that in investigations using balance tests with unanticipated external perturbations, participants are more reliant on sensory feedback from the peripheral receptors (16), possibly resulting in balance becoming biased towards participants with better reactive abilities than strength. Taube et al. (16) showed that muscle activation and ground reaction force is higher in drop jumps when participants were familiar with test conditions as opposed to conditions that were altered during the actual trial.

A more powerful lower extremity could possibly predispose a participant towards greater reach performance through three possible mechanisms. First, due to the stretch shortening

cycle (SSC) being a component of vertical jump tests (76, 86), players who jumped higher could possibly possess a more efficient SSC. A more efficient SSC could aid the players in storing elastic energy as they load their hip and knee extensors in the descent when performing the reaching movement, possibly potentiating the concentric phase (the return of the reach leg back to the starting position). However, it is unlikely that the SSC, which is dependent on a rapid eccentric phase and a quick transition to the concentric phase (87), is invoked during the YBT, possibly due to the perceived slowness and precise movement that is employed during the reach task. Second, findings of a significant correlation between countermovement jump height and greater muscle stiffness ($r = 0.55$, $p = 0.05$) (88) could mean that the higher the participant jumped, the better his lower extremity would be at absorbing energy from internal destabilising forces (i.e. gravity acting on the reaching limb), possibly minimizing postural sway whilst balancing (89) enabling a greater reach distance. However if body sway in the YBT occurred in the medial-lateral direction then the muscle stiffness of the abductor/adductor group will play a greater role (1) than the knee and hip extensors muscles. Third, and a more probable explanation is that experts regard power as the best index of coordinated human performance (49). Therefore participants with a greater CMJ_H are probably better able to maximally recruit the lower extremity muscles in a coordinated manner during a vertical jump test (90). Similarly, muscle coordination is needed to generate supportive reactions for maintaining balance (17). In the YBT, coordination is required within each leg, with knee and hip joint flexion acting together to predict between 78-94% of maximal reach (69). Therefore participants who had a greater CMJ_H are probably better able to control the hip and knee flexion moments in a synchronised fashion as they performed a maximal reach (31). Practically, football activities may demand power and coordinated movements in situations where a player is required to rapidly recruit the muscles of the knee, hip and ankle extensors in order to direct the body's COG to a more stable

position in order to remain balanced (17). However, dynamic balance on the dominant leg seems to be independent of lower extremity power.

An observation that lower extremity power had a stronger and more significant correlation with dynamic balance in the professional group than the university group can support the argument that in professional footballers, coordinated use of the lower extremity has an important role to play in functional movements.

5.5 The relationship of power and eccentric strength with dynamic balance on the dominant versus non-dominant limb

Although not one of the primary outcomes of the study, it may still be important to explain the finding that eccentric strength of knee extensors (in the university group only) or greater countermovement jump height (both groups) had a more significant and stronger relationship with reach performance on the non-dominant compared to the dominant leg.

It is important to point out that the results of this study as well as in numerous other studies (8, 27, 91) show that balance between the dominant and non-dominant legs in footballers is insignificant. Therefore, balance ability does not seem to be affected by limb dominance. However the neuromuscular strategy used in order to achieve this symmetry may be dissimilar.

The lower extremities are often treated equally to make data collection and analysis easier (92). As discussed, Paterno et al. (33) and Muelbauer et al. (30) assessed dynamic balance on the dominant leg and found no correlations with isokinetic strength and power, respectively. In contrast, Erkmen et al. (28) observed a significant negative correlation between single leg balance on the non-dominant leg in the BESS with CMJ_H. As mentioned, Lockie et al. (35) observed a significant strength and normalised reach differences on the left leg, compared to the right leg between better and lesser balanced participants. However, it should be noted that there is an assumption that most of the sample were right leg dominant. Santos et al. (58) demonstrated that eccentric training increased knee extensor strength and distance in functional hop tests with the non-dominant leg showing a larger and more significant improvement at post test and compared to that of the dominant leg.

Findings have shown that each limb system is specialised for controlling different characteristics of performance with the dominant leg preferred for manipulative type tasks, whilst the non-dominant leg provides postural stability as the complimentary role action (93). These different roles may alter the physiological and mechanical properties of the skeletal muscle in the dominant and non-dominant leg. There is evidence that daily preferential use of the hands for different tasks has been shown to alter the motor control strategy of the first dorsal interosseous muscle of the dominant hand, with the force build up occurring more gradually and at a slower firing rate (94). More specifically, Wang (92) observed that balance during the gait cycle is affected by limb dominance, with the non-dominant leg showing a greater variability with respect to vertical ground reaction forces and medial-lateral displacements of the centre of pressure.

There are more single leg stances performed on the non-dominant than dominant leg during football (27), due to football players preference to kick using the dominant leg (95). These stance phases are characterised by a forceful loading of the stance leg as the player kicks the ball (96). If the human motor system adapts to the needs of a task with great plasticity (94), then this could imply that different neural control strategies might develop between the lower limbs of the footballers due to their constant use of their non-dominant leg to stabilise as they execute a kicking action with the dominant leg. The familiarity of this action could in turn lead to a feed forward system of control being utilised ensuring that optimal recruitment of the leg extensors can be developed in the non-dominant leg in order to maintain a stable platform whilst kicking. However, different motor strategies may be utilised for balancing on the dominant limb, possibly predisposing athletes with better a sensory feedback control to balance better.

However, the influence of genetic factors on the lateralisation of the motor system cannot be ruled out. Previc (97) put forward that the antigravity extension on the non-dominant leg develops before neuromuscular dominance on the contra lateral side, possibly due to an asymmetry in vestibular functioning during prenatal development.

5.6 Limitations

First, isokinetic strength testing of the hip extensors may have added further practical value, providing a better overall picture of the strength demands of the YBT. Hip flexion angles have accounted for 14-58% of the variance in the three directions of the YBT (69). This can explain the EMG activation of the gluteal muscles which ranges between 21 – 49 % of MVIC in the reach movements (34). Furthermore, as mentioned, there is greater activation of the

biceps femoris in posterior reach directions, due its role in eccentrically resisting the increasing hip moment with further reach distance (31). Second, this study did not include a control group. Therefore it is difficult to ascertain whether the significant positive correlation between dynamic balance on the non-dominant leg with lower extremity strength and power may be due to football being mainly an asymmetrical sport or due to other vestibular factors suggested by Previc (97). Third, in hindsight, power could have been tested unilaterally, i.e. with a single-leg hop test. This may have given more insight into the power capabilities within each leg and a direct correlation could have been made with balance on the dominant and non-dominant leg.

5.7 CONCLUSION

This study found a significant relationship between eccentric strength of the knee extensors and dynamic balance in the YBT, in male university football players. This finding can be attributed to balance strategies that demand strength in the knee musculature that coordinate the compensatory movements during the reach (31). However, no relationship between the same experimental variables was observed in the professional group of footballers. This may be due to the possibility of either isokinetic single joint testing not being movement specific enough to correlate with functional performance in highly skilled footballers (82, 83) or different kinematic strategies adopted by this group. In both sample groups, it was concluded that the variables of eccentric strength of the knee flexors and dynamic balance are independent of each other. The knee flexors have a primary function as a knee joint stabilizer in weight bearing activities (34) and therefore are probably less dependent on strength to achieve their purpose. Additionally, lower extremity power had a significant positive relationship with reach performance in the professional group. Interestingly, in both groups, participant jump height had a stronger and more significant relationship with reach

performance on the non-dominant leg compared to that of the dominant limb. This highlights the coordinative aspect of the lower extremity extensor musculature, essential to controlling the joint torques as a player performs in dynamic situations, especially when balancing on the non-dominant leg. The non-dominant leg is used in more single leg stance phases while the dominant leg is shooting or passing during football. This may imply that different neural control strategies are developed which lead to an optimal recruitment of the leg extensors to maintain a stable platform whilst kicking.

However, it would be important to point out that maintaining balance in dynamic situations is complex and this is reflected by the moderate correlations observed in this study. Many factors contribute to the role of maintaining balance in dynamic situations (17). More studies may be needed in the future to identify additional performance variables related to dynamic balance. Additionally, further investigations can corroborate the relationship between eccentric strength and power with dynamic balance on the non-dominant leg in athletes of different sports and gender.

5.8 PRACTICAL APPLICATIONS

First, it is important to note that correlation studies give insight into relationships and not causation (83). However, finding a significant correlation is the first step towards establishing cause and effect. Holistic pre-season interventions aimed at improving or restoring single-leg balance in football players should include plyometric drills to improve power of the lower extremity. Eccentric strengthening of the knee extensor muscle group should still be incorporated due to the important role that eccentric contractions play in dynamic balance. Greater eccentric strength and power of the lower extremity may improve overall balance

which could lead to less injuries and improve kicking accuracy with the dominant leg (22). However, improvements in balance through strength and power training may be more noticeable on the non-dominant leg. However, a longitudinal study is still needed to measure the effects of eccentric strength and power training on dynamic balance in footballers.

5.9 Future research recommendations

Recommendations for future YBT studies should include EMG analysis for two reasons. First EMG analysis could give investigators insight into the activation levels, onset times and recruitment patterns between the dominant and non-dominant leg. Although studies have investigated EMG recordings during the performance in the YBT and SEBT (31, 34), there has been no comparison between the dominant and non-dominant legs. EMG amplitude differences between legs could infer dependence on strength and power of the non-dominant limb to balance. Second, EMG would give investigators insight into the activation levels between the knee extensor and hip extensor muscle groups during the reach movements, which can be used to support the relationships that they might find between strength and dynamic balance in these joints.

REFERENCES:

1. Winter DA. Human balance and posture control during standing and walking. *Gait and Posture*. 1995;3:193-214.
2. Nashner LM. Practical biomechanics and physiology of balance. In: Jacobson G, Newman CW, Kartush JM, editors. *Handbook of Balance Function Testing*. San Diego: Singular Publishing Group. 1997:261-79.
3. Flanagan SP. Balance and stability. In: Miller T, editor. *NSCA's Guide to Tests and Assessments*. USA: Human Kinetics. 2012:295-315.
4. Brown L, editor. *Isokinetics in Human Performance*: Human Kinetics; 2000.
5. Prentice WE. Open-versus closed chain-kinetic exercise in rehabilitation. In: Prentice WE, editor. *Rehabilitation Techniques for Sports Medicine and Athletic Training*. New York: McGraw-Hill Companies, Inc. 2004:242-62.
6. Enoka RM. Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology*. 1996;81(6):2339-46.
7. Butler RJ, Southers C, Gorman PP, Kiesel KB, Plisky PJ. Differences in soccer players' dynamic balance across levels of competition. *Journal of Athletic Training*. 2012;47(6):616-20.
8. Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic training*. 2007;42(1):42-6.
9. Gribble PA, Hertel J. Considerations for normalizing measures of the star excursion balance test. *Measurement in Physical Education and Exercise Science*. 2003;7(2):89-100.

10. Lindstedt SL, LaStayo PC, Reich TE. When active muscles lengthen: Properties and consequences of eccentric contractions. *News in Physiological Sciences*. 2001;16:256-61.
11. Horak FB. Postural Orientation and equilibrium: what do we need to know about the neural control of balance to prevent falls? *Age and Ageing*. 2006;35(S2):ii7-ii10.
12. Yim-Chiplis PK, Talbot LA. Defining and measuring balance in adults. *Biological Research for Nursing*. 2000;1(4):321-31.
13. Pollock AS, Durward BR, Rowe PJ, Paul JP. What is balance? *Clinical Rehabilitation*. 2000;14:402-6.
14. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*. 2005;35(3):213-34.
15. Bompa TO, Haff GG. Strength and power development. In: Bompa TO, Haff GG, editors. *Periodization: Theory and methodology of training*. Fifth ed. United States of America: Human Kinetics. 2009:259-85.
16. Taube W, Leukel C, Gollhofer A. How neurons make us jump: The neural control of stretch shortening cycle movements. *Exercise and Sports Sciences Reviews*. 2012;40(2):106-15.
17. Guskiewicz KM, Perrin DH. Research and clinical applications of assessing balance. *Journal of Sport Rehabilitation*. 1996;5:45-63.
18. Hrysomallis C. Balance ability and athletic performance. *Sports Medicine*. 2011;41(3):221-32.
19. Gerbino PG, Griffin ED, Zurakowski D. Comparison of standing balance between female collegiate dancers and soccer players. *Gait and Posture*. 2007;26:501-7.

20. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of Soccer: An update. *Sports Medicine*. 2005;35(6):501-36.
21. Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic training*. 2006;41(2):172-6.
22. Chew-Bullock TS, Anderson DI, Hamel KA, Gorelick ML, Wallace SA, Sidaway B. Kicking performance in relation to balance ability over the support leg. *Human Movement Science*. 2012;31:1615-23.
23. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic and Sports Physical Therapy*. 2006;36(12):911-9.
24. Hrysomallis C, Mclaughlin P, Goodman C. Balance and injury in elite Australian footballers. *International Journal of Sports Medicine*. 2007;28:844-7.
25. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic balance performance and noncontact lower extremity injury in college football players: An Initial study 2013 10 November 2013; 5(5):[417-22 pp.]. Available from:
<http://sph.sagepub.com/content/5/5/417.full.pdf+html>.
26. Lehr ME, Plisky PJ, Butler RJ, Fink ML, Kiesel KB, Underwood FB. Field-expedient screening and injury risk algorithm categories as predictors of noncontact lower extremity injury. *Scandinavian Journal of Medicine and Science in Sports*. 2013;23:225-32.
27. Matsuda S, Demura S, Uchiyama M. Centre of pressure sway characteristics during static one-legged stance of athletes from different sports. *Journal of Sports Sciences*. 2008;26(7):775-9.

28. Erkmen N, Taskin H, Sanioglu A, Kaplan T, Basturk D. Relationships between balance and functional performance in football players. *Journal of Human Kinetics*. 2010;26:21-9.
29. Johnson TK, Woollacott MH. Neuromuscular responses to platform perturbations in power- versus endurance-trained athletes. *Perceptual and Motor Skills*. 2011;112(1):3-20.
30. Muehlbauer T, Gollhofer A, Granacher U. Association of balance, strength, and power measures in young adults. *Journal of Strength and Conditioning Research*. 2013;27(3):582-9.
31. Earl JE, Hertel J. Lower-extremity muscle activation during the star excursion balance tests. *Journal of Sport Rehabilitation*. 2001;10:93-104.
32. Thorpe JL, Ebersole KT. Unilateral balance performance in female collegiate soccer athletes. *Journal of Strength and Conditioning Research*. 2008;22(5):1429-33.
33. Paterno MV, Schmitt IC, Ford K, Hewett T, editors. Contribution of lower extremity strength and postural stability to performance on the star excursion balance test. *Sports Physical Therapy Section Abstracts 2009: Journal of Orthopaedic and Sports Physical Therapy*.
34. Norris B, Trudelle-Jackson E. Hip- and thigh-muscle activation during the star excursion balance test. *Journal of Sport Rehabilitation*. 2011;20:428-41.
35. Lockie RG, Schultz AB, Callaghan SJ, Jeffriess MD. The effects of isokinetic knee extensor and flexor strength on dynamic stability as measured by functional reaching. *Isokinetics and Exercise Science*. 2013;21:301-9.

36. Lockie RG, Schultz AB, Callaghan SJ, Jeffries MD. The relationship between dynamic stability and multidirectional speed 2013 8 November 2013. Available from: http://www.researchgate.net/publication/255951788_The_Relationship_between_Dynamic_Stability_and_Multidirectional_Speed.
37. Behm D, Wahl J, Button D, Power K, Anderson K. Relationship between hockey skating speed and selected performance measures. *Journal of Strength and Conditioning Research*. 2005;19(2):326-31.
38. Mononen K, Kontinen N, Viitasalo J, Era P. Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. *Scandinavian Journal of Medicine and Science in Sports*. 2007;17:180-5.
39. Guskiewicz KM. Regaining postural stability and balance. In: Prentice WE, editor. *Rehabilitation Techniques for Sports Medicine and Athletic Training*. 4th ed. New York: McGraw-Hill Companies, Inc. 2004:156-85.
40. Massion J. Postural control system. *Current Opinion in Neurobiology*. 1994;4:877-87.
41. Horak FB, Nashner LM. Central programming of postural movements: Adaptation to altered support-surface configurations. *Journal of Neurophysiology*. 1986;55(6):1369-81.
42. Kovacs MS, Roetert EP, Ellenbecker TS. Efficient deceleration: The forgotten factor in tennis-specific training. *Strength and Conditioning Journal*. 2008;30(6):58-69.
43. Potthast W, Heinrich K, Schneider J, Brueggemann G. The success of a soccer kick depends on run up deceleration. 28 International Conference on Biomechanics in Sport: ISBS - Conference Proceedings Archive; 2010.

44. Kellis E, Katis A, Gissis I. Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Medicine and Science in Sports and Exercise*. 2004;36(6):1017-28.
45. Paillard T, Bizid R, Dupui P. Do sensorial manipulations affect subjects differently depending on their postural abilities. *British Journal of Sports Medicine*. 2007;41:435-8.
46. McCurdy K, Langsford G. The relationship between maximal unilateral squat strength and balance in young adult men and woman. *Journal of Sports Science and Medicine*. 2006;2006(5):282-8.
47. Gualtieri D, Cattaneo A, Sarcinella R, Cimadoro G, Alberti G. Relationship between balance capacity and jump ability in amateur soccer players of different ages. *Sport Sciences for Health*. 2008;3:73-6.
48. Hesari AF, Maoud G, Ortakand SM, Nodehi MA, Nikolaidis P. The relationship between the star excursion balance test and lower extremity strength, range of motion, and anthropometric characteristics. *Medicina Sportiva*. 2013;17(1):24-8.
49. Peterson MD. Power. In: Miller T, editor. *NSCA's Guide to Tests and Assessments*. United States: Human Kinetics. 2012:217-52.
50. Perry M, Carville S, Smith I, Rutherford O, Newham D. Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology*. 2007;100:553-61.
51. Skelton D, Kennedy J, Rutherford O. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. *Age and Ageing*. 2002;31:119-25.
52. Orr R, de Vos N, Singh N, Ross D, Stavrinou T, Fiatarone-Singh M. Power training improves balance in healthy older adults. *Journal of Gerontology*. 2006;61 A(1):78-85.

53. Woollacott MH, Tang P-F. Balance control during walking in the older adult: Research and its implications. *Physical Therapy*. 1997;77:646-60.
54. Neptune RR, Wright IC, Van den Bogert AJ. Muscle coordination and function during cutting movements. *Medicine and Science in Sports and Exercise*. 1999;31(2):294-302.
55. Madigan M. Age-related differences in muscle power during single-step balance recovery. *Journal of Applied Biomechanics*. 2006;22:186-93.
56. Anderson M, Gieck J, Perrin D, Weltman A, Rutt R, Denegar C. The relationships among isometric, isotonic, and isokinetic concentric and eccentric quadriceps and hamstring force and three components of athletic performance. *Journal of Orthopaedic and Sports Physical Therapy*. 1991;14:114-20.
57. Baldon M, Lobato D, Carvalho L, Wun P, Presotti C, Serrao F. Relationships between eccentric hip isokinetic torque and functional performance. *Journal of Sport Rehabilitation*. 2012;21:26-33.
58. Santos HH, Ávila MA, Hanashiro DN, Camargo PR, Salvini TF. The effects of knee extensor eccentric training on functional tests in healthy subjects. *Brazilian Journal of Physical Therapy*. 2010;14(4):276-83.
59. Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *Journal of American Geriatrics Society*. 1991;39(12):1194-2000.
60. Carter ND, Khan KM, Mallinson A, Janssen PA, Heinonen A, Petit MA, et al. Knee extension strength is a significant determinant of static and dynamic balance as well as quality of life in older community-dwelling women with osteoporosis. *Gerontology*. 2002;48:360-8.

61. Tsang W, Hui-Chan C. Comparison of muscle torque, balance, and confidence in older Tai Chi and healthy adults. *Medicine and Science in Sports and Exercise*. 2005;280-8.
62. Gribble PA, Hertel J, Denegar CR, Buckley WE. The effects of fatigue and chronic ankle instability on dynamic postural control. *Journal of Athletic training*. 2004;39(4):321-9.
63. Robbins S, Waked E, Gouw GJ, McClaran J. Athletic footwear affects balance in men. *British Journal of Sports Medicine*. 1994;28(2):117-22.
64. Gribble PA, Tucker WS, White PA. Time-of-day influences on static and dynamic postural control. *Journal of Athletic training*. 2007;42(1):35-41.
65. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy*. 2009;4(2):92-9.
66. Gribble PA, Hertel J, Plisky P. Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic training*. 2012;47(3):339-57.
67. Kinzey SJ, Armstrong CW. The reliability of the star excursion balance test in assessing dynamic balance. *Journal of Orthopaedic and Sports Physical Therapy*. 1998;27(5):356-60.
68. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the star excursion balance test: Analyses of subjects with and without chronic ankle instability. *Journal of Orthopaedic and Sports Physical Therapy*. 2006;36:131-7.
69. Robinson R, Gribble P. Kinematic predictors of performance on the star excursion balance test. *Journal of Sport Rehabilitation*. 2008;17:347-57.

70. Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the star excursion balance test. *Archives of Physical Medicine and Rehabilitation*. 2008;89:364-70.
71. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research*. 2004;18(3):551-5.
72. Slinde F, Suber C, Suber L, Edwen CE, Svantesson U. Test-retest reliability of three different countermovement jumping tests. *Journal of Strength and Conditioning Research*. 2008;22(2):640-4.
73. Moir G, Button C, Glaister M, Stone MH. Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *Journal of Strength and Conditioning Research*. 2004;18(2):276-80.
74. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Physical fitness, injuries, and team performance in soccer. *Medicine and Science in Sports and Exercise*. 2004;36(2):278-85.
75. McLellan CP, Lovell DI, Gass GC. The role of rate of force development on vertical jump performance. *Journal of Strength and Conditioning Research*. 2011;25(2):379-85.
76. Bosco C, Luhtanen P, Komi P. Simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology*. 1983;50(2):273-82.
77. Castagna C, Castellini E. Vertical jump performance in Italian male and female national-teams soccer players. *Journal of Strength and Conditioning Research*. 2013;27(4):1156-61.

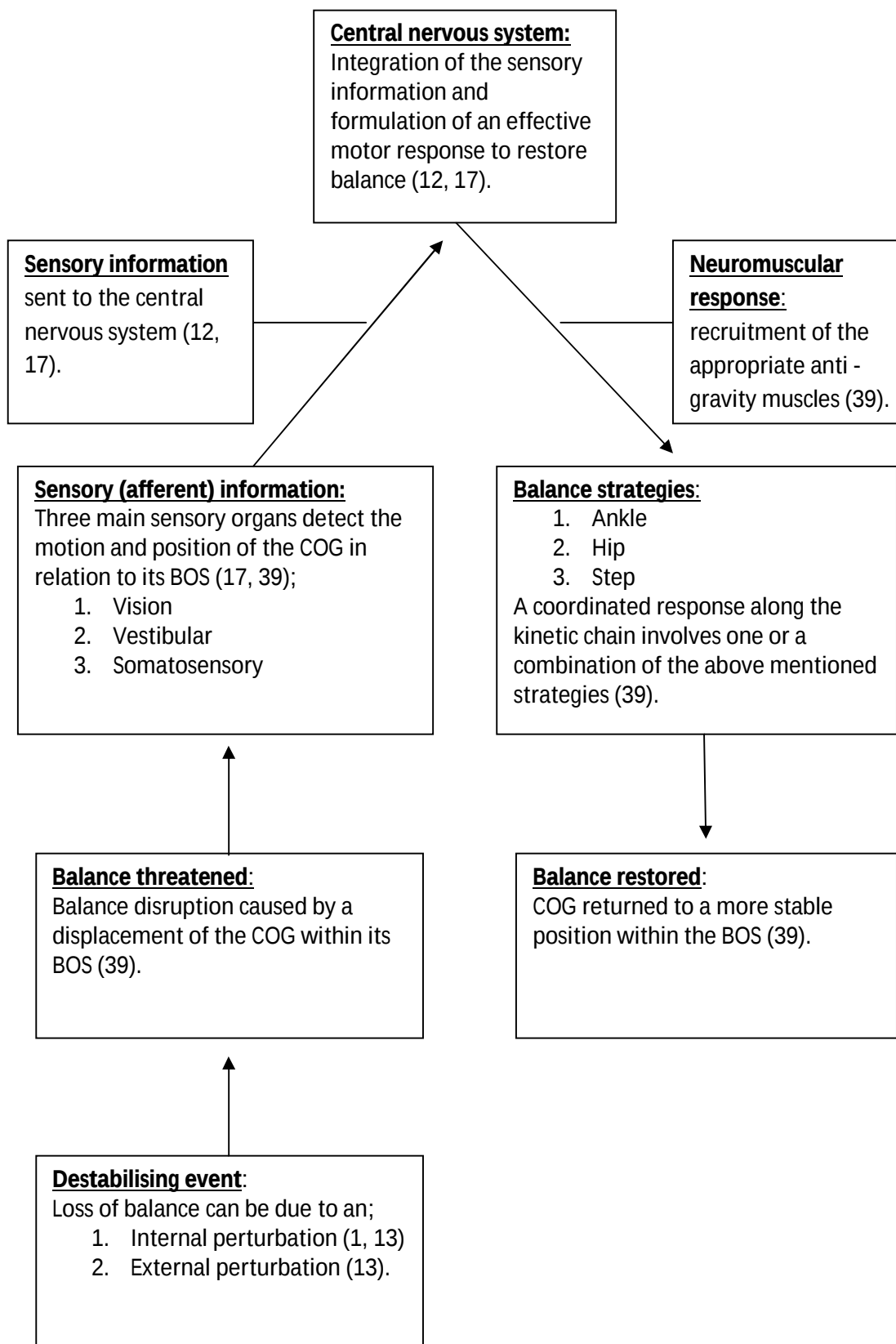
78. Perrin D. Open chain isokinetic assessment and exercise of the knee. *Journal of Sport Rehabilitation*. 1994;3:245-54.
79. Almosnino S, Stevenson JM, Bardana DD, Diaconescu ED, Dvir Z. Reproducibility of isokinetic knee eccentric and concentric strength indices in asymptomatic young adults. *Physical Therapy in Sport*. 2011;30:1-7.
80. Drouin J, Valovich-McLeod T, Shultz S, Gansneder B, Perrin D. Reliability and validity of the Biodex sytem 3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology*. 2004;91:22-9.
81. Plisk SS. Speed, agility and speed-endurance development. In: Baechle TR, Earle RW, editors. *Essentials of Strength Training and Conditioning 3ed*. United States: Human Kinetics. 2008:457-85.
82. Wisloff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical height jump in elite soccer players. *British Journal of Sports Medicine*. 2004;38:285-8.
83. Requena B, Gonzalez-Badillo JJ, de Villareal ES, Erelina J, Garcia I, Gapeyeva H, et al. Functional performance, maximal strength and power characteristics in isometric and dynamic actions of lower extremities in soccer players. *Journal of Strength and Conditioning Research*. 2009;23(5):1391-401.
84. Miller JP, Croce RV. Analyses of isokinetic and closed chain movements for hamstring reciprocal coactivation. *Journal of Sport Rehabilitation*. 2007;16:319-25.
85. Shields RK, Madhavan S, Gregg E, Leitch J, Petersen B, Salata S, et al. Neuromuscular control of the knee during a resisted single-limb squat exercise. *American Journal of Sports Medicine*. 2005;33(10):1520-6.

86. Bosco C, Komi PV. Mechanical characteristics and fiber composition of human leg extensor muscles. *European Journal of Applied Physiology*. 1979;41:275-84.
87. Komi PV, Gollhofer A. Stretch reflexes can have an important role in force enhancement during SSC exercise. *Journal of Applied Biomechanics*. 1997;13(4):451-9.
88. Bojsen-Moller J, Magnusson SP, Rasmussen LR, Kjaer M, Aagaard P. Muscle performance during maximal isometric and dynamic contractions is influenced by stiffness of the tendinous structures. *Journal of Applied Physiology*. 2005;99:986-94.
89. Blackburn T, Guskiewicz KM, Petschauer MA, Prentice WE. Balance and joint stability: The relative contributions of proprioception and muscular strength. *Journal of Sport Rehabilitation*. 2000;9:315-28.
90. Rodacki ALF, Fowler NE, Bennett SJ. Vertical jump coordination: fatigue effects. *Medicine and Science in Sports and Exercise*. 2002;34(1):105-16.
91. Gstottner M, Neher A, Scholtz A, Millonig M, Lember S, Raschner C. Balance ability and muscle response of the preferred and nonpreferred leg in soccer players. *Motor Control*. 2009;13:218-31.
92. Wang Y, Watanabe K. Limb dominance related to the variability and symmetry of the vertical ground reaction force and center of pressure. *Journal of Applied Biomechanics*. 2012;28:473-8.
93. Velotta J, Weyer J, Ramirez A, Winstead J, Bahamonde R. Relationship between leg dominance tests and type of task. *Portuguese Journal of Sport Sciences*. 2011;11(2):1035-8.
94. Adam A, De Luca CJ, Erim Z. Hand dominance and motor unit firing behavior. *Journal of Neurophysiology*. 1998;80:1373-1382.

95. Carey DP, Smith G, Smith DT, Shepherd JW, Skriver J, Ord L, et al. Footedness in world soccer: an analysis of France '98. *Journal of Sports Sciences*. 2001;19:855-64.
96. Lees A, Barton G, Robinson M. The influence of Cardan rotation sequence on angular orientation data for the lower limb in the soccer kick. *Journal of Sports Sciences*. 2010;28(4):445-50.
97. Previc FH. A general theory concerning the prenatal origins of cerebral lateralization in humans. *Psychological Review*. 1991;98(3):299-334.

APPENDIXES

Appendix A: Diagrammatic representation of the maintenance of balance



Appendix B: Participant's information sheet

Title: **The relationships between lower extremity eccentric strength and power with dynamic balance in male, university football players.**

Dear Participant,

I, Marc Booysen, am doing research on dynamic balance in football players at Wits University. Research is just the process to learn the answer to a question. In this study, I want to learn if there is a relationship between eccentric leg strength and power with dynamic balance in football players.

I would like to invite you to participate in a research study to investigate dynamic balance in football players. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you would like to be involved in the research. Thank you for reading this.

I will be conducting the research with two research assistants at the Centre for Exercise Science and Sports Medicine at the University of the Witwatersrand.

The aim of the research is to look at possible relationships between lower extremity eccentric strength and power with dynamic balance in footballers. Football players with better balance are reported to have a reduced risk from suffering lower leg injuries and perform at a superior level. I would like to see if these players have greater leg strength and power than players with less balance. This study has the potential of getting a better understanding of factors that may have a relationship with dynamic balance which may help reduce the risk of injuries and improve balance.

The reason you have been asked to participate is that you are all football players at Wits University and are older than 18, and younger than 22 years of age.

The study involves testing the following:

1. Filling in a medical history questionnaire:
This is to ensure that you are not carrying any injuries that could affect your results.
1. Anthropometrical measurements
Here your body mass and leg lengths will be measured.
2. Dynamic balance:
Your dynamic balance will be assessed using the star excursion balance test. This involves standing on one leg and then reaching as far as possible with the opposite foot in three different directions without losing your balance. Both your left and the right leg will be tested.
3. Leg power:

The counter movement jump will assess the maximum explosive power your legs can generate. This test is often used as a measure of athletic ability. Here you will need to jump as high as you possibly can. We will measure the average of three jumps.

4. Eccentric leg strength:

In this test you will be seated upright on a Biodex isokinetic machine and need to perform a maximal eccentric (where you resist a force) knee flexion and extension movement. You will perform 2 sets of 5 reps per leg.

All these tests will require maximal performance. There is a very small possibility of pulling a muscle during the three performance tests. You may also experience some muscle soreness about 24 to 48 hours after the test, this is normal, however, being a well conditioned athlete the muscle soreness is expected to be minimal.

The whole testing process will take between 60 – 80 minutes.

There is no reimbursement for being involved in the study.

Once the results have been analysed, you will receive a personal report with your results. Individual results will be kept in a safe place and will not be made known to anyone. All the participant's names will remain anonymous so that all data and results are confidential. The results of this study may be written up into academic report however, you as a participant will not be identified. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law.

Should you feel that your rights have been violated, you may report this to the Wits REC chairperson, Professor Cleaton-Jones. Email: peter.cleaton-jones@wits.ac.za

I would therefore like to invite you to participate in this study. Your permission to perform these tests is strictly voluntary. Should you do decide to take part, you will be given a consent form to sign and are still free to withdraw from the study at any time without giving a reason and without detriment to yourself.

Your participation in this study would be greatly appreciated.

Questions about the procedures used are encouraged. If you have any questions please contact me on: Cell: 082 495 7691 or Email: Marc.Booyesen@wits.ac.za

Thank you,

Marc Booyesen

Appendix C: Ethics approval



UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

R14/49 Mr Marc J Booysens

CLEARANCE CERTIFICATE

M120707

PROJECT

The Relationships between Lower Extremity
Eccentric Strength and Power with Dynamic
Balance in Male University Soccer (Football)

Players

INVESTIGATORS

Mr Marc J Booysens.

DEPARTMENT

Centre for Exercise & Sports Medicine

DATE CONSIDERED

27/07/2012

DECISION OF THE COMMITTEE*

Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 15/08/2012

CHAIRPERSON


(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Ms E Watson

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Appendix D: Ethics amendment

Human Research Ethics Committee (Medical)
(formerly Committee for Research on Human Subjects (Medical))

Secretariat: Research Office, Room SH10005, 10th floor, Senate House • Telephone: +27 11 717-1234 • Fax: +27 11 339-5708
Private Bag 3, Wits 2050, South Africa

University
of the Witwatersrand,
Johannesburg



02 December 2013

Mr Marc Booysens
Centre for Exercise Science and Sports Medicine
Education Campus
University

Sent by email to marc.booysens@wits.ac.za

Dear Mr Booysens

RE: Protocol M120707: "The Relationship between Eccentric Strength and Power with Dynamic Balance in male University Football Players"
Protocol amendment

This letter serves to confirm that the Chairman of the Human Research Ethics committee (Medical) has reviewed and approved your request to "use anonymous retrospective data from 27 professional players" as detailed in your letter dated 25 November 2013.

Thank you for keeping us informed and updated.

Yours sincerely,

Anisa Reshav
Administrator
Human Research Ethics Committee (Medical)

Appendix E: Participant's medical questionnaire:

Personal and sporting details:	
Participant's code:	Age:
Number of years playing:	
Do you currently participate in any other sport or training? Please circle: YES NO	
If "yes", please state which sport/training:	
Past participation in any sport or training (other than football)? Please circle: YES NO	
If "yes", please state which sport/training:	

Participant's Medical Information (Please tick appropriate box)			
Yes	No	Unsure	
			Has your doctor ever said that you have heart trouble?
			Do you feel pain in your chest when you do physical activity?
			In the past month, have you ever had chest pain when you were not doing physical exercise?
			Are you currently experiencing any confusion, disorientation, dizziness, nausea?
			Do you currently have any uncorrected visual problems or vestibular problems?
			Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
			Have you suffered a concussion or any type of head injury in the last three months?
			Do you currently have an upper respiratory tract infection?
			Have you had any lower limb injuries (e.g. sprained ankle, muscle or ligament tears, joint pain et cetera) that required medical attention in the last six months?
			Do you know of any other reason why you should not do physical activity?

Please turn over

[illegible]

Appendix F: Informed consent for university team

Title: The relationships between lower extremity eccentric strength and power with dynamic balance in male, university football players.

Dear Participant,

The aim of this study is to look at the relationships between lower extremity eccentric strength, power with dynamic balance.

I, as the participant want to confirm:

1. I am volunteering of my own accord.
2. I am aware of the procedures of the research and a research member has made me aware of the nature, benefits and risks involved during the research.
3. I have also been provided with a written information sheet explaining the study and have been given the time to discuss the research with a member of the research team.
4. I as the participant am aware that the results of the research will be kept confidential and safe and the results will be put into the study report and may be written up into academic reports.
5. I am also aware that I can withdraw from the study at anytime without prejudice, from any further study.

Please sign the consent this form below. If there are any questions or concerns they will be answered by the researchers.

Mr Marc Booysen, 082 495 7691, Marc.Booyesen@wits.ac.za

Mrs Estelle Watson Estelle.watson@wits.ac.za

Mr Philippe Gradidge Philippe.Gradidge@wits.ac.za

Please return the completed form to your coach. All data collected will be kept in a safe, locked environment so to maintain confidentiality of the information provided.

Thank you again for the opportunity for being involved in this research.

I have read the above and understand all the information about the research that is being done to investigate the relationships between lower extremity eccentric strength, power with dynamic balance.

I consent to participate in this study.

Signature of participant: _____ Date: _____

Signature of witness: _____ Date: _____

INFORMED CONSENT FORM

UNIVERSITY OF WITWATERSRAND

Centre for Exercise Science and Sports Medicine

EXPLANATION OF THE TESTS

2. Isokinetic tests:

A biokineticist of the Centre for Exercise Science and Sports Medicine will be conducting the required isokinetic strength testing on the Biodex system 3 dynamometer and its attachments.

The testing procedure will take about an hour depending on what is required. The following will be done in the testing:

- Weight
- Proper warm up of the limb being tested ($\pm$ 10 minutes)
- Stretching of limb prior to testing
- Explanation to the client/patient about the testing procedure.
- Familiarisation of each protocol prior to maximal testing of the limb

b) Physical tests:

CESSM staff or supervised students may conduct a number of evaluations such as height, weight, girth measurements, skin fold thickness, speed, agility and other fitness or performance parameters.

c) Medical examinations

You may be asked to undergo a medical history and examination, which will be conducted by qualified and registered medical practitioners. This will follow routine procedures, and sport specific assessments.

d) Other professional assessments

Depending on the programme that you are undergoing, there may be additional professional assessments, and may include:

- o Mental skills / psychology
- o Nutrition / dietetics
- o Optometry / sports vision
- o Podiatry
- o Physiotherapy
- o Other

2. ATTENDANT RISKS AND DISCOMFORTS

It is of utmost importance that any current injuries and any pain the client/patient is currently experiencing are known prior to testing procedures. This information should be shared with the tester beforehand and after consultation with the referring/resident clinician the final testing protocol will be decided.

Isokinetic testing - due to the nature of the testing, there is always the risk of muscle or joint injury during concentric and eccentric maximal tests if the client/patient does not warm-up adequately or is carrying an injury. This risk is however less if the client/patient follows the prescribed test protocol completely.

Performance tests: - due to the nature of physical activity in some, there may be physiological muscle discomfort. The other tests pose no risk to the individual.

Medical examinations: - there are no risks to the individual in undergoing a medical examination

Other professional evaluations: - there are no risks to the individual

3. RESPONSIBILITIES OF THE PARTICIPANT

It is important that the clients/patients/athletes follow the instructions of the tester completely throughout the testing time-period. The clients/patients/athletes should be completely rested and should not have trained maximally at all for at least 12 hours before testing session. This is important for the accuracy of the measurements.

4. BENEFITS TO BE EXPECTED

With injury assessments and where relevant a referring clinician will receive a brief summary of the test results, which he/she will be able to explain to the client/patient following the testing session.

5. INQUIRIES

The clients/patients/athletes may feel free to ask any questions regarding the testing procedure at any time during, before or after the testing procedures.

6. USE OF MEDICAL RECORDS and CONFIDENTIALITY

The information obtained during the testing procedures will be treated as privileged and confidential. It will not be released or revealed to any person except your referring clinician without your written consent. Results of individuals will be made to the client/patient/athlete themselves. Group results may be made available to relevant stakeholders (federation, corporation etc) but will not reveal individual details. The information obtained, however, may be used for research and statistical analyses for scientific purposes with your right to privacy retained.

7. FREEDOM OF CONSENT

If clients/patients/athletes feel the need to withdraw from testing, they may feel free to do so at any time. Notice of this decision should however be given to the clinician involved.

CONSENT:

I confirm that the above-mentioned tests have been thoroughly explained to me. I acknowledge that the personal information required by the clinician and those derived from the testing procedures will remain strictly confidential and no reference to my name will be revealed in any publication or statistical analysis. I have read this form and I understand the testing procedures that I will have to perform, my rights as a client/patient and the attendant risks, complications and discomforts. Knowing these risks, complications and discomforts, and having the opportunity to ask questions that have been answered to my satisfaction, I

consent to participate in this testing and offer my full cooperation. I further indemnify the Centre for Exercise Science and Sports Medicine against any form of legal action resulting from possible injuries sustained during the testing procedure.

DATE:

NAME (CLIENT/PATIENT):

SIGNATURE (CLIENT/PATIENT):

DATE:

NAME (WITNESS):

SIGNATURE (WITNESS):

DATE:

NAME (TESTING CLINICIAN):

SIGNATURE (TESTING CLINICIAN):

Appendix H: Data collection sheet:

Code	
------	--

Date of test	
Time of testing	

Age			
Height			
Body mass			
Leg length R		3 x LL =	
Leg length L		3 x LL =	
BMI			
Dominant leg			

YBT balance test:

Anterior direction	1 st trial	2 nd trial	3 rd trial	Average
Right (cm)				
Left (cm)				

Posteromedial direction	1 st trial	2 nd trial	3 rd trial	Average
Right (cm)				
Left (cm)				

Posterolateral direction	1 st trial	2 nd trial	3 rd trial	Average
Right (cm)				
Left (cm)				

Normalised reach on right	$A + PM + PL / 3 \times \text{right leg length} \times 100 =$	%
Normalised reach on left	$A + PM + PL / 3 \times \text{left leg length} \times 100 =$	%

Composite score	$R + L / 2 =$	%
-----------------	---------------	---

Counter movement jump:

Trial 1	Trial 2	Trial 3	Average	Max

Isokinetic testing:

	Right leg	Left leg	Mean ($R = L / 2$)
Extensor PT/BW			
Flexor PT/BW			