2012

A kinanthropometric analysis of accurate and inaccurate kickers: Implications for kicking accuracy in Australian football

Nicolas H. Hart
Edith Cowan University

USE OF THESIS

A KINANTHROPOMETRIC ANALYSIS OF ACCURATE AND INACCURATE KICKERS: IMPLICATIONS FOR KICKING ACCURACY IN AUSTRALIAN FOOTBALL.

NICOLAS H. HART

BSC (EXSPSC), CSCS, ESSAM

A THESIS SUBMITTED TO EDITH COWAN UNIVERSITY

IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF:

MASTERS BY RESEARCH (SPORTS SCIENCE)

SCHOOL OF EXERCISE AND HEALTH SCIENCES

EDITH COWAN UNIVERSITY

DATE OF SUBMISSION: MARCH, 2012

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i). Incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

(ii). Contain material previously published or written by another person except where due reference is made in the text; or

(iii). Contain any defamatory material.

Signature:

Date: 6th March 2012

ACKNOWLEDGEMENTS

There are many people I wish to thank and acknowledge, for I would not have survived this intense and prolonged journey without their encouragement, advice, support and friendship.

To my family, and in particular my loving parents, Pamela and Graeme – Words simply cannot express my eternal gratitude for your understanding, love and support (emotional and financial) through-out my entire life to date. Needless to say, this is as much my thesis as is it yours. Thank you so much for never doubting my professional aspirations, no matter how unfeasible or irrational they often seemed. I love you all very much, and always will.

To my supervisors (past and present), Dr Jodie Cochrane, Dr Sophia Nimphius, Prof. Robert Newton and Dr Prue Cormie – Thank you all so much for your dedication to my cause. You have each inspired me, and continue to inspire me to pursue greatness. The opportunities I have been afforded through-out my time with each of you have been remarkable and so genuinely appreciated. In particular, Jodie and Sophia, I cannot thank you enough for your belief in me as a student, a researcher and a friend. You were ‘saving graces’ during a very tough and tumultuous time, and I am eternally grateful to you both!

To our wonderful Lab Technicians, Nadija Vrdoljak and Jack Burns – It goes without saying that this School simply would not function without such fantastic lab technicians. My project was certainly no ‘walk in the park’ to organise, set-up and manage, and the support and assistance shown by both of you was incredible. Thank you both so much.

To my fellow postgraduates, thank you for your regular advice and support. In particular, Harry Banyard, your frequent fun, jokes and laughter were always fantastic. You were a genuinely positive influence in my time at ECU. If only there were more people like you!

To a valued friend, Tania Spiteri – I don’t think I would have survived this thesis, and all that has taken place these last two years, had it not been for you. We have, together, experienced some of the most unique, interesting and ironic moments anyone could ever dream of. Suffice to say, this will be a lifelong memory, and you a lifelong friend. Thanks!

ABSTRACT

A paucity of research exists investigating the potential relationship between the technical and temporal strategy of accurate and inaccurate kickers in response to physical parameters modifiable by athletic conditioning. While recent studies have produced improvements in performance when kicking for distance following structured resistance training interventions, no studies have examined the influence of such interventions on the enhancement of kicking accuracy. It was therefore the purpose of this thesis to extend scientific understanding of those mechanisms which might underpin accurate kicking performances through examining kinanthropometric, strength and muscularity profiles of accurate and inaccurate kickers in Australian Football using a series of research studies. In particular, studies one and two established valid and reliable measurement protocols, while studies three, four and five quantified whole-body composition, anthropometrics, segmental masses of the lower limbs, unilateral and bilateral lower-body strength, and lower limb kinematics during the drop punt.

Study one established a standardised and reliable body positioning and scan analysis model using Dual Energy X-ray Absorptiometry (DEXA) to accurately identify and assess appendicular segmental mass components (upper arm, forearm, hand, thigh, shank and foot segments); producing very high intra-tester reliability (CV $\leq$ 2.6%; ICC $\geq$ 0.941) and very high inter-tester reliability (CV $\leq$ 2.4%; ICC $\geq$ 0.961). This methodological determination of intralimb and interlimb quantities of lean, fat and total mass could be used by strength and conditioning practitioners to monitor the efficacy of training interventions; track athletes during long-term athletic development programs; or identify potential deficiencies acquired through-out injury onset and during rehabilitation.

Study two assessed a portable isometric lower-body strength testing device, successfully demonstrating its ability to derive valid and reliable representations of maximal isometric force (peak force) under bilateral and unilateral conditions (CV ≤ 4.7%; ICC ≥ 0.961). This device was unable to reliably determine rate of force development across either bilateral or unilateral conditions (CV: 14.5% - 45.5%; ICC: 0.360 – 0.943); and required an extra second of contraction time to achieve peak force ($p < 0.001$). The portable apparatus may provide a more sport-specific assessment of maximal strength in sports where balance is an important component; such as the support leg during the kicking motion.

Using the methodological approach established in study one; study three was a descriptive study which assessed the lower limb segmental profile of accurate and inaccurate kickers. A noticeable difference in leg mass characteristics was evident, with accurate kickers containing significantly greater quantities of relative lean mass ($p \leq 0.004$; $r = 0.426$ to 0.698), significantly lower quantities of relative fat mass ($p \leq 0.024$; $r = -0.431$ to -0.585), and significantly higher lean-to-fat mass ratios ($p \leq 0.009$; $r = 0.482$ to 0.622) across all segments within both kicking and support limbs. To examine how these lower limb characteristics might adjust biomechanical strategy; study four used the methodological approach from study one in conjunction with three-dimensional kinematic data. No relationship was found between foot velocity and kicking accuracy ($r = -0.035$ to -0.083). Instead, it was the co-contribution of leg mass and foot velocity which were discriminatory factors between accurate and inaccurate kickers. A significant and strong correlation was also found between relative lean mass and kicking accuracy ($p \leq 0.001$; $r = 0.631$). Greater relative lean mass within accurate kickers may heighten limb control due to reduced volitional effort and lower relative muscular impulses required to generate limb velocity.

Study five - the final study of the thesis - assessed lower limb strength and muscularity using methodologies presented in studies one and two. Study five was able to successfully demonstrate a positive relationship between relative bilateral strength and support-leg unilateral strength with kicking accuracy outcomes (r = 0.379 to 0.401). A significant negative relationship was established between strength imbalances and kicking accuracy ($p = 0.002$; $r = 0.516$), supported by the significant positive relationship between the limb symmetry index for lean mass quantities and kicking accuracy outcomes (p = 0.003 to 0.029; r = 0.312 to 0.402). This highlighted the potential benefit of greater limb symmetry for strength and muscularity between kicking and support limbs within Australian Footballers, with particular emphasis placed toward support leg strength.

The general conclusion provided by the thesis promotes the importance and positive influence of relative lean mass and lower body strength to kicking accuracy production during the drop punt. The findings provide a valid rationale for strength and conditioning professionals and skill acquisition coaches to properly consider an athlete's strength, muscularity and body mass profiles when attempting to improve kicking performance. Given the cross-sectional nature of the Thesis, longitudinal resistance training studies should be attempted in future, to establish interventions which may heighten athletic conditioning and technical proficiency in football sports, with an express aim to improve drop punt kicking accuracy.

PUBLICATIONS ARISING FROM THIS THESIS

Published:

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2012). *Reliability and validity of unilateral and bilateral isometric strength measures using a customised, portable apparatus.* Journal of Australian Strength and Conditioning. 20 (Suppl. 1), 61-67.

In Review:

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2012). *A standardised in-vivo method to identify and assess appendicular segmental mass using Dual Energy X-Ray Absorptiometry (DEXA).* Sports Biomechanics.

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2012). *Leg Mass Characteristics of Accurate and Inaccurate Kickers: An Australian Football perspective.* Journal of Sports Sciences.

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2012). *The influence of leg mass and foot velocity on kicking accuracy in Australian Football.* Journal of Motor Behavior.

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2012). *Does lower limb symmetry enhance technical proficiency? A kicking perspective.* Journal of Sports Sciences.

Conference Presentation:

Hart, N.H., Nimphius, S., Cochrane, J.L., & Newton, R. U. (2011). *Reliability and validity of unilateral and bilateral isometric strength measures using a customised, portable apparatus.* Paper presented at the International Conference on Applied Strength and Conditioning, Gold Coast, QLD, Australia.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter Five

Chapter Six

Chapter Seven

LIST OF TABLES

Chapter Four

Chapter Five

Chapter Six

Chapter Seven

LIST OF ABBREVIATIONS

2D	**-**	Two-dimensional
3D	-	Three-dimensional
AFL	-	Australian Football League
BL	-	Bilateral
BLD	-	Bilateral Deficit
BMI	-	Body Mass Index
BMS	-	Ballistic Measurement System
cm	-	Centimetre
CV	-	Coefficient of Variation
deg/s	-	Degrees per second
DEXA	-	Dual Energy X-ray Absorptiometry
ES	**-**	Effect Size
ft	-	Feet
g	-	Gram
ICC	-	Intraclass Correlation Coefficient
kg	-	Kilogram
KL	-	Kicking Leg, Unilateral
LFR	-	Lean-to-Fat Ratio
m	-	Metre
mm	**-**	Millimetre
MF	-	Mean Force
N	-	Newtons

PF	-	Peak Force
PPM	-	Pearsons Product Moment
R	-	Intraclass Correlation Coefficient
r	-	Pearsons Product Moment Correlation Coefficient
RFD	-	Rate of Force Development
SD	-	Standard Deviation
SI	-	Symmetry Index
SL	-	Support Leg, Unilateral
TTPF	-	Time to Peak Force
ULD	-	Unilateral, Dominant
ULN	-	Unilateral, Non-Dominant
WAFL	-	Western Australian Football League
yrs	-	Years

1.0 - CHAPTER ONE - INTRODUCTION

1.1. Background

Kicking is a fundamental and defining skill in football sports, routinely employed to achieve effective ball progression and successful scoring sequences (Lees, Asai, Andersen, Nunome & Sterzing, 2010; Young et al, 2010; Kellis & Katis, 2007a; Hoskins & Pollard, 2003). As the effectiveness of a single kick can often differentiate between winning and losing a competitive match; the ability to kick a ball accurately, over a desired distance, to an intended target or location remains a critical component of an athlete's skill-set (Young et al, 2010; Ball, 2007a; Reilly & Doran, 2001, Orchard, Walt, McIntosh & Garlick, 1999). Despite the evident importance of kicking accuracy in football sports, a scarcity of research has been produced describing the biomechanical or physiological characteristics which might modify or mediate kicking accuracy production (Young et al, 2010; Sterzing, Lange, Wachtler, Muller & Milani, 2009; Hennig, Althoff & Hoemme, 2009; Dichiera et al, 2006; Teixeira, 1999).

While the kicking action requires complex and multidimensional whole body interactions to be successful (Lees et al, 2010; Naito, Fukui & Maruyama, 2010; Rath, 2005; Shan & Westerhoff, 2005); the primary end-points that influence and determine ball velocity, trajectory and directionality involve the generated foot velocity, effective striking mass of the limb, and quality of foot-ball contact established at the moment of ball impact (Lees et al, 2010; Young & Rath, 2011; Anderson & Dorge, 2009; Ball, 2008; Ball, 2007b; Kellis & Katis, 2007a). Given that the air pressure of the ball remains relatively unchanged due to game-based specifications (Ball, 2008); the time and distance of contact between the foot and ball is largely dependent upon the generated foot velocity and striking mass characteristics of the kicking limb (Naito et al, 2010; Andersen & Dorge, 2009; Sterzing & Hennig, 2008; Kellis & Katis, 2007a; Andersen, Dorge & Thomsen, 1999; Tsaousidis & Zatsiorsky, 1996), which are modifiable through structured training interventions (Young & Rath, 2011; Ball, 2007b; Perez-Gomez et al, 2008a).

In particular, previous research has focused attention towards the enhancement of kicking distance, using biomechanical and physiological interventions to improve the magnitude of generated foot velocity and mechanical work produced during foot-ball impact (Young & Rath, 2011; Ball, Smith & MacMahon, 2010; Lees et al, 2010; Naito et al, 2010; Baktash et al, 2009; Smith, Ball & MacMahon, 2009; Ball, 2008; Ball, 2007a; Ball, 2007b; Sterzing & Hennig, 2008; Kellis & Katis, 2007a; Baker & Ball, 1996; Tsaousidis & Zatsiorsky, 1996). However, much less is known about the potential influence of these characteristics on the production of kicking accuracy (Young et al, 2010; Dichiera et al, 2006; Sterzing et al, 2009). Despite an evident improvement in maximal kicking distance following multi-joint, dynamic lower body strength and power training programs (Campo et al, 2009; Perez-Gomez et al, 2008a; Manolopoulos, Papadopoulos & Kellis, 2006; Manolopoulos, Papadopoulos, Salonikidis, Katartzi & Poluha, 2004), prior research has yet to identify whether such programs will yield positive or negative outcomes when kicking accuracy is the intention.

More specifically, the lower limb mass profile of an athlete could have a profound impact on their strength levels and kinanthropometric characteristics, which will subsequently adjust the biomechanical strategy and athletic behaviour necessary to generate successful kicking performances (Malina & Geithner, 2011; Nevill, Holder & Watts, 2009; Perez-Gomez et al, 2008b). In particular, strength and conditioning interventions may promote kicking accuracy for several reasons: 1) Increasing total mass of the kicking limb might allow a proportionate reduction in foot velocity at a given distance, which could optimise the speed-accuracy trade-off; 2) Increasing lean mass and total strength of the kicking limb may enable a proportionate reduction in relative muscular impulse to achieve a given distance, which may honour the impulse-variability theory (Urbin, Stodden, Fischman & Weimar, 2011; Schmidt & Lee, 2005); and 3) Increasing the lean mass, total mass and total strength of the support limb may improve athletic stability and force transference throughout the kicking motion. These proposed interactions represent only a few possible outcomes achievable through resistance training interventions, and highlight the need to increase the scientific and practical understanding towards the manner in which physical conditioning practices could improve kicking accuracy performance.

1.2. Purpose of Research

The primary purpose of the thesis was to examine the biomechanical and kinanthropometric characteristics of accurate and inaccurate kickers in Australian Football in order to identify the potential influences or mediators of kicking accuracy when performing the drop punt kick. In particular, this thesis has assessed whole body composition and anthropometrics; lower limb segmental mass; unilateral and bilateral leg strength; and lower limb kinematics of accurate and inaccurate Australian Footballers. A secondary function of this thesis was to establish a valid and reliable measurement protocol to locate and quantify segmental mass components of the lower limbs, as well as the ability to accurately assess maximal lower body strength using a less stable, portable and customised device.

1.3. Significance of Research

A paucity of research exists investigating the potential relationship between the technical and temporal strategy of accurate and inaccurate kickers in response to physical parameters which are modifiable by athletic conditioning. While previous studies have established notable improvements in performance outcomes when kicking for distance following structured resistance training interventions (Campo et al, 2009; Perez-Gomez et al, 2008a; Manolopoulos et al, 2006; Manolopoulos, et al, 2004), no studies have examined the influence of such interventions on the enhancement of kicking accuracy. As a result, this thesis serves to extend the scientific understanding of those mechanisms which underpin accurate kicking performances through examining the strength and muscularity profiles of accurate and inaccurate kickers in Australian Football.

It is anticipated that the information provided in this thesis will provide a valuable insight into the manner in which an athlete's strength and body mass characteristics could potentially adjust the biomechanical strategies and technical capabilities of footballers performing the drop punt kick under accuracy constraints. This will inevitably improve the quality of coaching, physical conditioning and skill acquisition strategies employed by sport scientists in the sporting landscape. Specifically, the acute, cross-sectional outcomes of this thesis could provide the basis for future longitudinal resistance training studies as a tool to establish strength and conditioning interventions targeted towards optimising technical proficiency and capability in football sports.

1.5. Research Questions

1) Can composite mass of the lower limbs be identified, segmented and assessed using a standardised, valid and reliable DEXA protocol?

2) Is a portable isometric strength device able to validly and reliably measure unilateral and bilateral expressions of strength and power?

3) Will leg mass characteristics of the kicking and support limbs differ between accurate and inaccurate kickers in Australian Football?

4) Are absolute quantities or relative quantities of lean and fat mass better correlated to drop punt kicking accuracy?

5) Is there a relationship between peak foot velocity and kicking accuracy when performing the drop punt?

6) Will a unilateral strength imbalance (lateral dominance effect) differentiate an accurate kicker from an inaccurate kicker in Australian Football?

7) Are absolute or relative bilateral and unilateral strength characteristics better correlated to drop punt kicking accuracy?

1.6. Research Studies

A series of five experimental studies have been developed to assess the kinanthropometric characteristics of Australian Footballers, including anthropometry; whole body composition; segmental masses of the lower limbs; unilateral and bilateral leg strength; and lower limb kinematics produced during the kicking action. The first two studies were necessary to establish standardised, valid and reliable measurement protocols when examining strength and muscularity profiles of athletes. These methods were subsequently used in the final three studies to quantify the necessary athletic characteristics required by this research, comparing accurate kickers with inaccurate kickers in Australian Football.

1.7. Limitations

1) The outcomes of this thesis are delimited to the cohort of subjects used; specifically male athletes participating in the Western Australian Football League, with a minimum of 5 years playing experience. The applications of these findings are therefore limited to this population, and might not transfer to other Australian Football competitions.

2) Although 5 years playing experience was a minimum requirement for study participation; a complete profile of training and playing history was not recorded. While athletes were recruited from the same league, their prior amount of practise could not be estimated, and might have held an undetermined influence on established outcomes.

3) A stationary player target over a short 20 metre distance was used to assess kicking accuracy. Due to the different constraints imposed upon athletes when kicking to different targets (goal versus player), and distances (short versus long), these findings are limited to a short distance kick towards a player target.

4) The kicking assessment was performed from an indoor laboratory, with the ball kicked through an open high-raised passage to a player target situated outside. While maximum kicking trajectory was not restricted, the width of the door and presence of expensive and sophisticated equipment surrounding the kicker may have influenced their kicking proficiency. The impact of this is believed to have been minimal as extensive familiarisation was provided.

2.0 - CHAPTER TWO - LITERATURE REVIEW

2.1. Overview

This literature review has been written to briefly introduce existing literature relating to the material which has been investigated and disseminated in subsequent chapters of this thesis. In particular, the literature review has been arranged to present a global overview of three key areas: 1) the prevalence of kicking in sport, with specific focus on the drop punt; 2) a detailed, full-body kinematic description of the drop punt; and 3) the biomechanical characteristics which mediate kicking distance and kicking accuracy performance. This review will conclude by outlining the current deficiencies in the literature, specifically concerning the description, influence and characteristics of kicking accuracy within football sports.

2.2. Kicking in Sport

Kicking is a fundamental skill which requires the co-ordinated integration of complex motor patterns in order to be skilfully performed; often established in predictive developmental stages (Naito et al, 2010; Magill, 2008; Teixeira, 1999; Davids, Lees & Burwitz; Barfield, 1998; Butterfield & Loovis, 1994). In the sporting environment, kicking actions are highly prevalent, with many technical variations routinely employed to achieve numerous competitive outcomes (Shaughnessy, 2006; Dawson, Hopkinson, Appleby, Stewart & Roberts, 2004; Appleby & Dawson, 2002). Football codes, in particular, legislate that ball progression and scoring sequences must be principally achieved through foot-to-ball interactions (Coventry et al, 2011; Young et al, 2010; Ball, 2007a; Kellis & Katis, 2007a; Andersen et al, 1999). Due to the volatile nature of competitive play, a multitude of kicking strategies are used to provide a tactical advantage within the boundaries of their sports (Ball, 2011; Sterzing & Hennig, 2008; Appleby & Dawson, 2002; Norton, Craig & Olds, 1999; Lees & Nolan, 1998), which may be broadly categorised as either place kicks or punt kicks, depending on the nature of ball position and delivery to the foot upon impact (Ball, 2011; Reilly & Doran, 2001; Lees & Nolan, 1998).

Specifically, place kicks require the ball to be struck from a kicking tee, or while positioned on the ground, and are primarily seen in Soccer, Rugby and American Football (Lees & Owens, 2011; Witt & Dorsch, 2009; Bezodis, Trewartha, Wilson & Irwin, 2007; Shan & Westerhoff, 2005). Due to various situational contexts, a multitude of technical expressions exist for the place kick; in soccer, place kicks can be classified based on loft, speed and spin, and include the side-kick, instep kick, chip kick and drive kick (Lees & Owens, 2011; Sterzing & Hennig, 2008; Kellis & Katis, 2007a; Smith, Gilleard, Hammond & Brooks, 2006; Dorge et al, 2002; McLean & Tumilty, 1993), while rugby codes use place kicks following an awarded penalty or successful try, subsequently requiring a conversion from a kicking tee (Baktash et al, 2009; Bezodis et al, 2007).

In contrast, punt kicks require the ball to be released by the hands and delivered to the foot, causing the ball to be struck while it is travelling through space (Ball, 2011; Pavely, Adams, Francesco, Larkham & Maher, 2010; Hosford & Meikle, 2007). Due to the inherently greater customisation and control of ball position during hand-release and foot-contact, a variety of techniques are available to punt kickers as tools to capitalise on tactically advantageous situations. In particular, these techniques fall under several classifications on the basis foot-ball contact and subsequent ball rotation through the air, leading to the production of spiral punts, check-side punts, stab punts, drop punts and drop kicks (Ball, 2011; Pavely et al, 2010; Ball 2008; Hosford & Meikle, 2007; Reilly & Doran, 2001). The most widely used kicking action across all football sports is the drop punt, featuring as a primary skill in Australian Football and Gaelic Football, while also employed as a secondary and tertiary skill in Rugby Union, Rugby League, Soccer and American Football (Ball, 2011; Lithorne & Patel, 2011; Dichiera et al, 2006; Reilly & Doran, 2001; Davids et al, 2000; Orchard et al, 1999).

2.3. Description of the Drop Punt

Characterised by the backward rotation of the ball through the air, around its transverse, longitudinal axis (Hosford & Meikle, 2007; Saliba & Hrysomalis, 2001); the drop punt is preferentially utilised by kickers in order to deliver a ball accurately, over a desired distance, to an intended target or location (Dichiera et al, 2006; Rath, 2005; Cameron & Adams, 2003; Saliba & Hrysomalis, 2001). The drop punt is relatively reliable, simple to execute and faster to perform when compared to other punting techniques (Ball, 2008; Orchard et al, 1999), providing better ball stability and predictability when travelling through the air (Ball, 2011; Hosford & Meikle, 2007), making it easier to catch by the player receiving the ball (Ball, 2011; Dichiera et al, 2006; Saliba & Hrysomalis, 2001; Orchard et al, 1999). The drop punt is therefore considered to be a desired element of any football player's skill-set (Ball, 2007a; Reilly & Doran, 2001; Orchard et al, 1999).

The drop punt is a complex and multidimensional kicking action which involves whole body interactions in order to be successful (Rath, 2005; Shan & Westerhoff, 2005). As such, to assist with technique analysis, interpretation and correction, the kicking action itself is able to be broken down into movement phases (Burkett, 2010; Smith et al, 2006;

Lees, 2002; Davids et al, 2000). Previous biomechanical analyses of various kicking actions have attempted to establish common phases evident between kicking styles, selectively using the behaviour of the kicking leg as the focal point of phase determination due to the identifiable and consistent movement pattern produced by this limb across kicking techniques (Ball, 2008; Reilly & Doran, 2001; Davids et al, 2000; Orchard et al, 1999). However, a lack of consensus exists between studies as to the precise number of phases used, and the points at which each phase commences. This lack of analytical consistency can complicate interpretive comparisons between studies in the literature. Regardless, Orchard and colleagues (1999) presents the most detailed and suitable phase-based criteria for biomechanical analysis of the drop punt in Australian Football (Reilly & Doran, 2001), with general descriptions provided in Table 1, while illustrated in Figure 1.

Table 1. Biomechanical movement phase criteria for the drop punt kick using critical moments of the kicking leg.

Phase of Movement	**Start Point**	**End Point**
Approach	Initiation of forward movement	Toe-off (into kicking action)
Back Swing	Toe-off (into kicking action)	Maximum hip extension.
Wind-Up	Maximum hip extension	Maximum knee flexion
Forward Swing	Maximum knee flexion	Foot-to-ball contact
Follow-Through	Foot-to-ball contact	Maximum knee extension
Recovery	Maximum knee extension	Maximum hip flexion

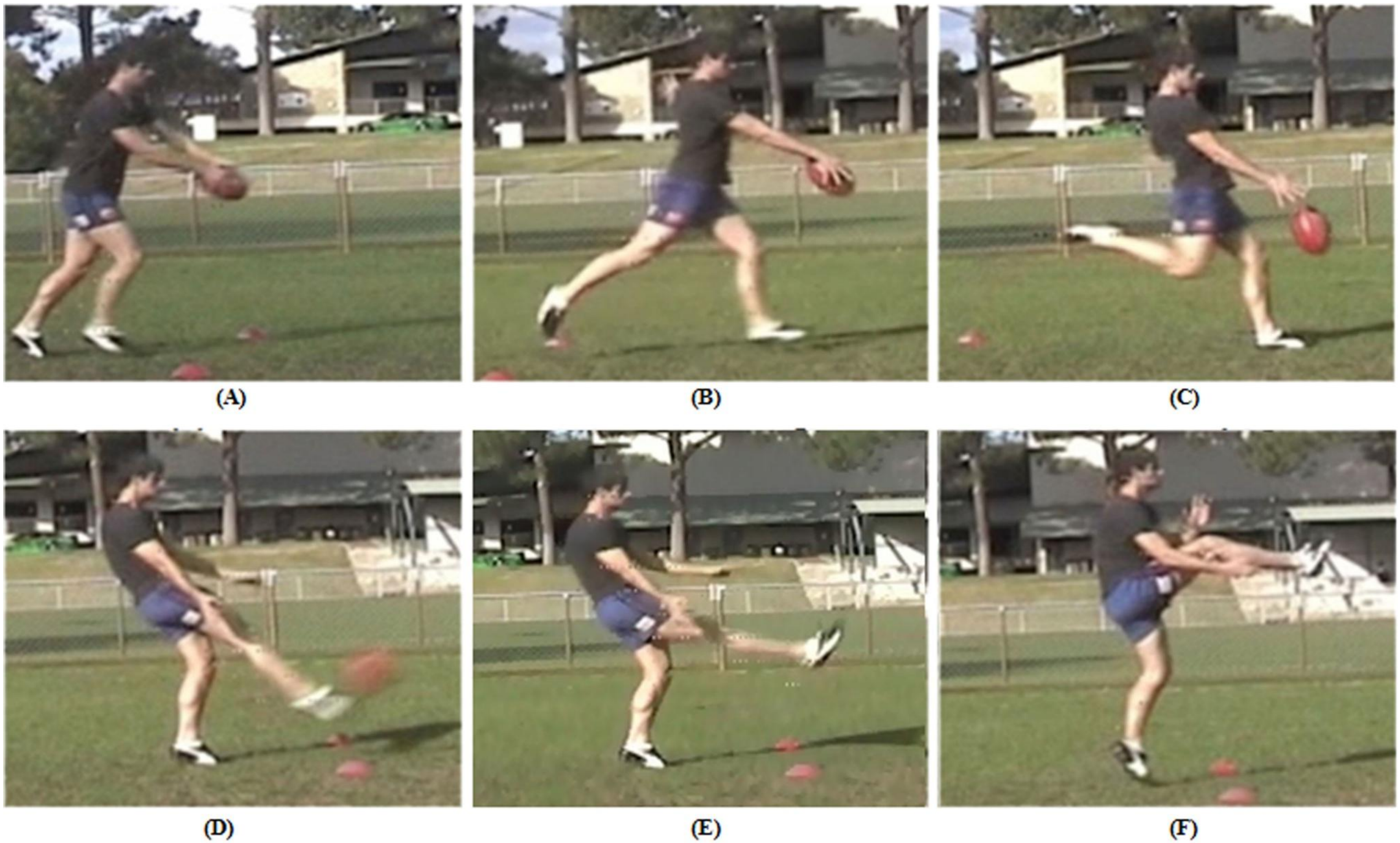


Figure 1. Phases of the drop punt: (A) approach, (B) backswing, (C) wind-up, (D) forward swing, (E) follow through, and (F) recovery.

2.4. Kinematic Profile of the Drop Punt

2.4.1. Biomechanical Characteristics

The principal aim of the drop punt is to project a ball accurately over a desired distance, at a desired velocity, to an intended target or location (Young et al, 2010; Hosford & Meikle, 2007; Dichiera et al, 2006). To achieve this outcome, appropriate force must be imparted onto the ball as a resultant function of generated foot velocity, effective striking mass, and the quality of foot-ball contact (Young & Rath, 2011; Andersen & Dorge, 2009; Ball, 2008; Sterzing & Hennig, 2008; Ball, 2007b; Cameron & Adams, 2003; Andersen et al, 1999). Given that correct kicking technique involves a series of well timed and controlled whole body interactions (Naito et al, 2010; Bezodis et al, 2007; Shan & Westerhoff, 2005; Davids et al, 2000); the successful execution of the drop punt is governed by a complex interaction of intrinsic biomechanical factors relevant to the entire body (Burkett, 2010; Naito et al, 2010; Hosford & Meikle, 2007; Rath, 2005; Shan & Westerhoff, 2005).

In particular, ball velocity, trajectory and directionality is the end-product of proximal-to-distal segmentation (Young & Rath, 2011; Kellis & Katis, 2007a; Reilly & Doran, 2001; Marshall & Elliot, 2000; Putnam, 1993; Putnam, 1991); limb co-ordination and control (Naito et al, 2010; Cameron & Adams, 2003; Davids et al, 2000; McLean & Tumilty, 1993); foot position, stiffness, and impact restitution (Young & Rath, 2011; Ball, 2007a; Cameron & Adams, 2003; Dorge et al, 2002; Andersen et al, 1999; Tsaousidis & Zatsiorsky, 1996); ball drop and contact position (Ball, 2011; Pavely et al, 2010; Hosford & Meikle, 2007); joint flexibility and range of motion (Hosford & Meikle, 2007; Young, Clothier, Otago, Bruce & Liddell, 2004); support leg behaviour (Hrysomalis, 2011; Baktash et al, 2009; Orloff et al, 2008; Barfield, 1998); and upper body behaviour (Pavely et al, 2010; Bezodis et al, 2007; Shan & Westerhoff, 2005).

Few formal scientific analyses of the drop punt have been produced to describe these characteristics, and the manner in which they influence the generation of foot velocity and foot-ball contact. Understanding the biomechanics of the kicking action can profoundly improve the coaching process (Smith et al, 2006; Lees, 2002; Barfield, 1998), and better direct future mechanical investigations necessary for improvements in performance and technique.

2.4.2. The Kicking Leg

Research has principally focused attention towards the behaviour of the kicking leg when investigating a variety of performance and technique based indicators concerning the place kick and punt kick in sport (Young & Rath, 2011; Andersen & Dorge, 2009; Ball, 2008; Kellis & Katis, 2007a; Dorge et al, 2002; Reilly & Doran, 2001; Lees & Nolan, 1998). In particular, the development of foot velocity, and subsequent foot-ball collision have developed into common technical themes apparent within the literature, suitably viewed as fundamentally important aspects of kicking performance (Young & Rath, 2011; Ball, 2008; Dorge et al, 2002; Andersen et al, 1999).

2.4.2.1. Foot Velocity

Foot velocity has been identified as a significant contributor to subsequent ball velocity and kicking distance achieved (Young & Rath, 2011; Campo et al, 2009; Ball, 2008; Perez-Gomez et al, 2008a; Rath, 2005; Baker & Ball, 1996), accounting for approximately 67%

of kicking distance variability when using the drop punt technique (Ball, 2008). In order to develop high foot speeds, the kicking leg must produce a proximal-to-distal segmental sequence, commonly identified as a 'throw-like' movement pattern (Lithorne & Patel, 2011; Dorge et al, 2002; Marshall & Elliot, 2000; Putnam, 1993; Putnam, 1991). Therefore, body segments involved in the kicking action are modelled as an open-linked system, through which the distal segment (the foot) moves freely through space (Andersen & Dorge, 2009; Nunome, Ikegami, Kozakai, Apriantono & Sano, 2006; Putnam, 1993; Putnam, 1991).

The production and magnitude of foot velocity established through proximal-to-distal segmentation can be best explained by the summation of speed theory (Figure 2), which states that to maximise foot speed, the movement should commence with the proximal segments (the body and thigh), and progress through the linked chain to more distal segments (the shank and foot) so that each segment starts its motion at the preceding segments moment of greatest velocity (Rath, 2005; Lees, 2002; Putnam, 1991). Therefore, the more distal a segment is, the faster it will eventually move (Orchard et al, 1999; Putnam, 1993).

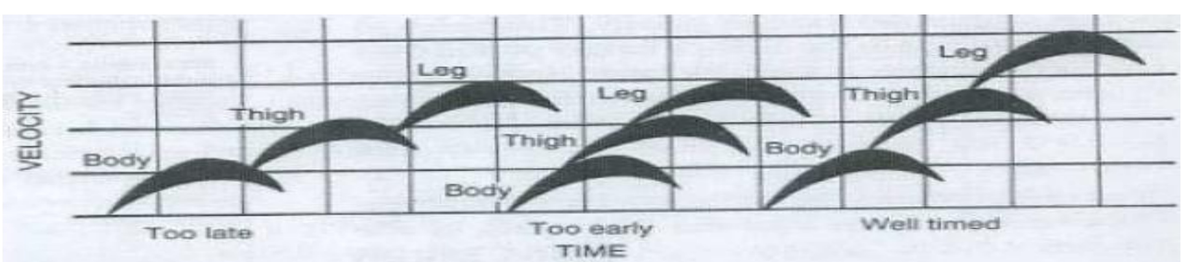


Figure 2. The summation of speed theory, illustrating correct and incorrect speed transfer and summation through proximal-to-distal sequencing (adapted from Rath, 2005).

This complex segmental interaction highlights the difficulties inherent within the kicking leg, as inefficiencies in limb control, co-ordination, joint range of motion and segmental timing can vastly influence the quality and magnitude of foot velocity produced (Lithorne & Patel, 2011; Kellis & Katis, 2007a; Davids et al, 2000; Dorge et al, 2002; McLean & Tumilty, 1993; Young et al, 2004).

2.4.2.2. Foot-ball Contact

The development of foot velocity does not wholly represent the complexity of the kicking action and the manner in which it generates ball velocity. More specifically, ball velocity, trajectory, and directionality rely upon the suitable generation of angular momentum transferred to the ball, and angular impulse applied to the ball, as created by the kicking leg during the kicking action and impact phase (Mungan, 2007; Nunome, Lake, Georgakis & Stergioulas, 2006; Dorge et al, 2002; Andersen et al, 1999; Levanon & Dapena, 1998; Tsaousidis & Zatsiorsky, 1996). In particular, several studies examining the collision between the foot and ball during place and punt kicking actions have identified that the transfer of angular momentum was not the only interaction responsible for ball velocity, demonstrating sufficient time in contact between the foot and ball for the application of angular impulse (torque x time) or mechanical work (mass x acceleration x distance) to also be prevalent (Smith, Ball & MacMahon, 2009; Enoka, 2008; Ball, 2007b; Andersen et al, 1999; Tsaousidis & Zatsiorsky, 1996).

Therefore a limb with greater striking mass or greater peak velocity at impact will achieve greater ball velocity due to a longer contact time between the foot and the ball (Young & Rath, 2011; Ball, 2007b; Andersen et al, 1999). Consideration must therefore be given to the effective striking mass of the kicking leg leading into contact between the foot and the ball (Baktash et al, 2009; Sterzing & Hennig, 2008; Rath, 2005; Andersen et al, 1999; Barfield, 1998), and the manner in which this modifies the quality of impact, and time of impact between these two rigid bodies (Ball, 2007b; Nunome et al, 2006b; Rath, 2005; Andersen et al, 1999). In particular, these qualities might adjust the degree of generated momentum transferred to the ball by modifying the coefficient of restitution (Young & Rath, 2011; Andersen et al, 1999; Tsaousidis & Zatsiorsky, 1996).

The coefficient of restitution is a measure of impact elasticity and momentum transfer between two rigid bodies, in this case, the foot and ball (Enoka, 2008; Dorge et al, 2002; Andersen et al, 1999). As such, the collision between the foot and the ball is influenced by the deformability or stiffness of the kicking foot (Young & Rath, 2011; Cameron & Adams, 2003), and the location of ball contact with the foot surface during the striking motion (Ball, 2011; Lithorne & Patel, 2011; Hosford & Meikle, 2007). Given that the swinging foot is fixed in plantarflexion at ball impact, with the ball positioned to connect with the ankle-foot complex (Sterzing & Hennig, 2008; Hosford & Meikle, 2007; Orchard et al, 1999), the exactness of ball delivery to the foot and quality of agonist-antagonist co-contraction at the ankle joint will determine whether the foot will deform or straighten (Young & Rath, 2011; Nunome et al, 2006; Lees & Nolan, 1998) and therefore whether the coefficient of restitution is increased or decreased (Young & Rath, 2011; Andersen et al, 1999). As a result, kicking performance for distance or accuracy may be jeopardised if there is a subsequent loss of limb control and reduction in ball velocity (Kellis & Katis, 2007a; Cameron & Adams, 2003; Barfield, 1998).

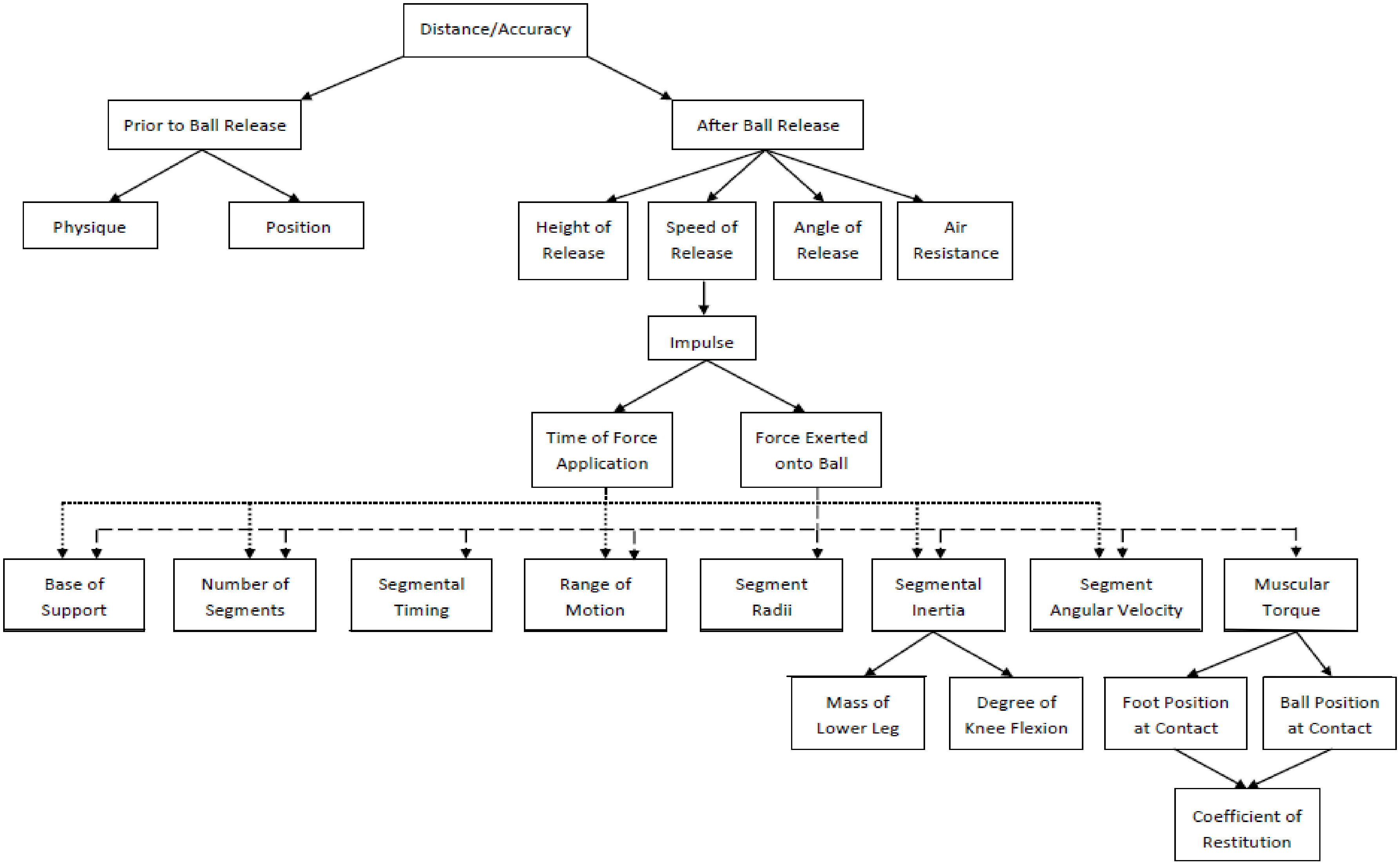


Figure 3.A deterministic biomechanical model of the Drop Punt when kicking for accuracy or distance.

2.4.3. The Support Leg

The support leg has received limited attention in the literature, with few studies investigating its behavioural characteristics and contributions to kicking performance (Young & Rath, 2011; Clagg et al, 2009; Dichiera et al, 2006). As skilled kicking involves the complex interaction of many body segments, and requires footballers to adopt unipedal postures (Paillard et al, 2006; Shan & Westerhoff, 2005; Kellis, Gerodimoss, Kellis & Manou, 2001); the wholesome contribution of the support leg to the kicking motion is visibly important, however remains largely undefined in punt kicking techniques to date (Young & Rath, 2011; Baktash et al, 2009; Rath, 2005; Orchard et al, 1999).

Preliminary findings demonstrate the importance of the support leg as a mechanism to allow athletes to manipulate and lower their centre of gravity in order to provide greater athletic stability, balance and control (Gstottner et al, 2009; Dichiera et al, 2006; Matsuda, Demura & Uchiyama, 2008), while also resisting torque developed by the kicking leg when powerfully striking the ball (Kubo, Muramatsu, Hoshikawa & Kanehisa, 2010; Clagg et al, 2009; Gerbino, Griffin & Zurakowski, 2007; Wong et al, 2007). In particular, the support leg is positioned in front of the athlete's centre of mass during the initial plant phase, prior to the forward rotational motion of the kicking leg, in order to act as an axis of rotation for the swinging limb (Baktash et al, 2009; Orloff et al, 2008; Barfield, 1998), and to also provide an external force (ground reaction force) necessary to commence the segmental sequencing of the kicking leg (Orloff et al, 2008; Sterzing & Hennig, 2008; Kellis, Katis & Gissis, 2004).

Some evidence has been provided to lend support for these functions, with skilful kickers demonstrating the ability to stabilise the hip and knee joints during active loading, while producing larger hip flexion and knee flexion angles during the kicking action so as to allow a more functional lowering of their centre of gravity (Clagg et al, 2009; Dichiera, et al, 2006; Rahnama, Lees & Bambaecichi, 2005). Skilful kickers also seemingly initiate contact with the ground using the heel of their foot and commence flexing at the knee, prior to fully planting the foot, leading to activation of the hip and knee muscles to lock the system (body) in place (Hosford & Meikle, 2007; Dichiera et al, 2006; Rahnama et al, 2005). The position of the plant leg and the forces in which it generates are therefore components which influence ball velocity and trajectory (Baktash et al, 2009; Orloff et al, 2008; Sterzing & Hennig, 2008; Kellis et al, 2004; Barfield, 1998).

2.4.4. The Upper Body

Kicking is not mechanically exclusive to the lower limbs (Pavely et al, 2010; Bezodis et al, 2007; Shan & Westerhoff, 2005), with noteworthy contributions from upper body segments, including the head, arms and trunk (Young & Rath, 2011; Hides et al, 2010; Marshall & Elliot, 2000; Lees & Nolan, 1998). While the kicking action is a whole body, multi-joint movement, these upper body interactions have been considerably neglected in the literature, with few quantitative or qualitative analyses available for all kicking techniques (Pavely et al, 2010; Rath, 2005; Shan & Westerhoff, 2005). In particular, no studies have quantified the upper body mechanics of punt kicking techniques which are characteristically different to place kicks on the basis of ipsilateral (kicking side) arm use during ball drop and delivery.

Preliminary findings, established from place kicking literature, acknowledges the significant contribution of the upper body to kicking effectiveness, with skilled kickers using greater trunk rotation and contralateral (non-kicking side) arm extension and abduction to produce a more effective tension and pre-lengthening stretch through the musculature of the trunk and pelvis, assisting with force generation and velocity transfer (Shan & Westerhoff, 2005; Lees & Nolan, 1998). This initial abduction by the contralateral arm also appears to provide preparatory stability at the moment of ball drop in punt kicking, prior to a synchronistically forward projection with the kicking leg, presumably for heightened dynamic, bilateral stability during the rapid striking action (Bezodis et al, 2009; Rath, 2005; Orchard et al, 1999).

Punt kicking, specifically, uses the ipsilateral arm to control ball drop and delivery to the foot, while assisting with balance and stability post release (Pavely et al, 2010; Hosford & Meikle, 2007; Rath, 2005). Together, with head position, trunk rotation, trunk lean, and contralateral arm activity; the augmentation and control of whole body angular momentum is able to be achieved (Baktash et al, 2009; Bezodis et al, 2007; Rath, 2005; Marshall & Elliot, 2000), subsequently producing greater generation and transfer of momentum through the kicking leg, and into the ball (Pavely et al, 2010; Baktash et al, 2009; Bezodis et al, 2007; Shan & Westerhoff, 2005). While practitioners attempt to theorise the role of the upper body segments during the kicking motion, formal scientific evidence remains scarce (Bezodis et al, 2007; Barfield, 1998; Lees & Nolan, 1998), demonstrating a need for further investigation.

2.4.5. Other Considerations

2.4.5.1. The Approach

The drop punt can be performed from either a stationary position, or through the use of a predetermined approach strategy, which may vary based on length, speed and angle of approach (Hosford & Meikle, 2007; Kellis & Katis, 2007a; Kellis et al, 2004). However, the speed and angle of approach form the two main components which can substantially influence kicking performance, specifically concerning the development of foot velocity and rotational axis of the kicking leg (Andersen & Dorge, 2009; Orloff et al, 2008; Kellis et al, 2004). In particular, the approach phase is a preparatory movement (Kellis & Katis, 2007a) that aims to suitably accelerate the body to a selected velocity, prior to planting the support leg, as a mechanism to generate and transfer greater levels of initial velocity from the whole body, through the sequential segmentation of the kicking leg, and into the ball (Andersen & Dorge, 2009; Ball, 2008; Hosford & Meikle, 2007).

Given that the generation of foot velocity is an important component in kicking performance (Ball, 2008; Sterzing & Hennig, 2008; Levanon and Dapena, 1998), and that segments of the kicking leg are influenced by whole body momentum developed during the approach (Andersen & Dorge, 2009); the speed of approach is an important characteristic to address. In particular, an established run-up approach achieves higher ball speeds than a stationary kick on the basis of previously established momentum, whereby an optimal, athlete-specific, self-determined approach speed appears to produce the greatest kicking outcomes (Andersen & Dorge, 2009). While the speed of approach is dependent on the step length and step frequency of the kicker (Andersen & Dorge, 2009), the last step length in particular, has been identified as an important contributor to foot speed, allowing greater lengthening of hip musculature, which subsequently enables them to perform more work over greater distance, in addition to the evident stretch-shorten effect on the muscle (Andersen & Dorge, 2009; Andersen et al, 1999).

Furthermore, it has been demonstrated in soccer-based literature that an angled approach is superior to a straight-line approach (Young & Rath, 2011; Kellis & Katis, 2007a; Barfield, 1998), suggesting an approach angle between 30 to 45° as optimal (Clagg et al, 2009; Kellis et al, 2004; Barfield, 1998; Lees & Nolan, 1998). This is believed to allow greater rotation of the pelvic girdle and greater hip extension, which may allow increased force production over a longer duration to enhance the velocity of the foot (Andersen & Dorge, 2009; Lees & Nolan, 1998). An angled approach also appears to yield greater directional accuracy when compared to the straight-line approach, as the adductor muscles of the kicking leg during straight-line kicking tend to drag the leg across the mid-line of the body, whereas the angled approach enables the rotational axis of the swinging limb to align with the target (Andersen & Dorge, 2009; Hosford & Meikle, 2007; Kellis et al, 2004).

The approach phase in Australian Football adopts the pace, tempo and kinematic profile of a traditional jogging action, and generally consists of 5 or more steps (Orchard et al, 1999; Mann, Moran & Dougherty, 1986), with athletes employing straight-line, side-step or angled approaches (Hosford & Meikle, 2007). While previous research has proposed the ideal approach strategy using a self-selected speed and an oblique approach angle; further research is needed to examine this using the drop punt kick in Australian Football.

2.4.5.2. Ball Trajectory

To project a ball over greater maximal distances the ball must be projected at an appropriate angle (Linthorne & Patel, 2011; Alam, Subic, Watkins & Smits, 2009). Traditional projectile motion theory suggests that the ideal angle of release is 45° (Linthorne & Patel, 2011; Enoka, 2008; Hall, 2007); however, consideration must also be given to the anticipated release height, landing height, and aerodynamics of the projectile, which may increase or decrease the optimal angle of release (Linthorne & Patel, 2011; Alam et al, 2009; Enoka, 2008; Hall, 2007). In the sporting environment, this relationship has been prominent, with optimal projection angles spanning between 26 – 39° for throwing sports, including shot-put, javelin, discus and soccer throw-ins (Leigh, Liu, Hubbard & Yu, 2010; Linthorne & Everett, 2006; Viitasalo, Mononen & Norvapalo, 2003; Hubbard, de Mestre & Scott, 2001; Linthorne, 2001); while also spanning between 19 – 27° for jumping sports, including the traditional long jump and standing long jump events (Linthorne, Guzman & Bridgett, 2005; Wakai & Linthorne, 2005), well below the conventional 45° angle of trajectory. Conversely, basketball jump shots can vary between 48 to 55° based on distance, due to the requirements of desirable angles of entry into the basket (Hall, 2007; Miller & Bartlett, 1996), which extends beyond the 45° idealism, highlighting the specificity of projectile angle, and projectile motion to precise sporting conditions.

In football sports, the optimal projection angle of punt kicks have been established to sit between 40 - 45° in soccer (Linthorne & Patel, 2011), and 31 - 39° in rugby union (Holmes, Jones, Hardland & Petzing, 2006). However, the punt kick in soccer does not appear to suitably represent the punt kick produced in Australian Football as the soccer ball is aerodynamically dissimilar to the spherical, ellipsoidal shaped ball present in Australian Football (Alam et al, 2009; Alam, Subic, Watkins, Naser & Rasul, 2008). Therefore, in Australian Football, the estimated optimal kicking trajectory to maximise distance is assumed to sit somewhere between 30 to 40° (Hosford & Meikle, 2007; Holmes et al, 2006). Specifically, the generated backward rotation and spherical shape of the ball in Australian Football considerably modifies its aerodynamic profile by creating a lift effect (Linthorne & Patel, 2011; Alam et al, 2009; Alam et al, 2008; Ball, 2011). This subsequently decreases the necessary kicking trajectory required to achieve maximal distances. A reduced kicking trajectory also has tactical advantages, as it enables a more direct travel-path for the ball to the target, leading to faster ball progression; improved penetration of defensive structures; and greater ball stability through air when kicking a goal (Ball, 2011; Linthorne & Patel, 2011; Ball, 2007a).

2.5. Kicking Performance

2.5.1. Kicking Distance

The ability to kick a ball over greater distances is an important skill to acquire in football sports (Young & Rath, 2011; Ball, 2007b; Baker & Ball, 1996), tactically enabling footballers to defensively clear the ball, improve penetration of opposition defences, and shoot for goal from more distant positions (Ball, 2011; Pavely et al, 2010; Ball, 2008; Ball, 2007b). In particular, players who are able to kick over longer distances are established as recruiting priorities in Australian Football (Ball, 2008), with longer effective kicks correlating highly to evident score differences between teams in the competitive environment (Ball, 2008; Ball, 2007b). In response to these notable advantages, research has attempted to describe and develop biomechanical strategies to optimise an athlete's ability to kick for distance, focusing primarily on the significant correlation ($p < 0.01$) between the development of foot velocity and subsequent ball velocity achieved (Young & Rath, 2011; Andersen & Dorge, 2009; Baktash et al, 2009; Sterzing & Hennig, 2008; Ball, 2008; Ball, 2007b; Kellis & Katis, 2007a; Masuda, Kikuhara, Demura, Katsuta & Yamanaka, 2005; Andersen et al, 1999; Baker & Ball, 1996).

In particular, athletes who achieved greater kicking distances in response to higher foot velocities exhibited several distinguishing biomechanical characteristics, including greater hip extension and knee flexion angles during the backswing and wind-up; as well as greater knee and shank velocities at ball impact (Ball, 2008; Levanon & Dapena, 1998; Baker & Ball, 1996). These outcomes are notably advantageous for two main reasons: 1) greater hip extension produces a larger pre-stretch (lengthening) of the hip flexors, which subsequently creates higher initial limb velocity in response to a greater stretch-shortening effect (Lees et al, 2010; Hosford & Meikle, 2007); and 2) greater knee flexion reduces the rotational inertia of the swinging limb, to promote greater angular thigh velocity during the wind-up and forward swing stages of the kick (Naito et al, 2010; Ball, 2008). As a result, both characteristics have previously been able to generate greater knee, and shank velocities in response to an effective and well-timed proximal-to-distal segmental sequence (Naito et al, 2010; Andersen & Dorge, 2009; Putnam, 1993; Putnam, 1991)

While foot velocity is a significant contributor to ball velocity, it is not an exclusive factor, as the quality of foot-ball contact must also be considered (Ball, 2008; Kellis & Katis, 2007a; Andersen et al, 1999; Levanon & Dapena, 1998; Baker & Ball, 1996). During the impact phase, the ball is able to remain in contact with the foot for up to 10 - 16 milliseconds, subsequently allowing for an approximate knee extension of up to 8 - 20° (Ball, 2007a; Tsaousidis & Zatsiorsky, 1996). As a result, the strength and power profile of the hip flexors and knee extensors might successfully produce an additive effect to the attainment of ball velocity, through the creation of greater foot velocity during the swing phase, and through the application of greater muscular work on the ball during the contact phase (Young & Rath, 2011; Ball 2007a; Andersen et al, 1999). Furthermore, assuming velocity remains unchanged, a limb with greater total mass (effective striking mass) will be able to generate higher ball velocity; therefore, another potential intervention may seek to specifically increase lean muscle mass, as this should enable an increase in total limb mass without compromising limb velocity (Young & Rath, 2011; Ball, 2008; Hosford & Meikle, 2007), however, this has yet to be assessed in kicking literature to date.

Due to the evident contribution and importance of lower limb muscle mass in the production of maximal, high velocity kicking actions (Perez-Gomez et al, 2008a; Perez-Gomez et al, 2008b; Ball 2007a; Kellis & Katis, 2007b; Dorge et al, 2002; Dorge et al, 1999; Orchard et al, 1999; Lees & Nolan, 1998), several studies have attempted to examine whether a relationship exists between lower limb strength and kicking performance using isokinetic dynamometry (Kellis & Katis, 2007b; Masuda et al, 2005; Masuda, Kikuhara, Takahashi & Yamanaka, 2003; Cometti, Maffiuletti, Pousson, Chatard & Maffulli, 2001; Saliba & Hrysomalis, 2001; Aagaard, Simonsen, Trolle, Bangsbo & Klausen, 1996; Aagaard, Simonsen, Trolle, Bangsbo & Klausen, 1994; Mognini, Narici, Sirtori & Lorenzelli, 1994). Unfortunately, the contradictory findings from these studies tentatively render the potential relationship between strength and foot velocity as unclear. However, it must be acknowledged that the lack of specificity inherent within isokinetic single-joint testing modalities likely accounts for this lack of conclusiveness, as kicking based muscle function is bi-articular, generating multi-segmental, multi-joint movements (Young & Rath, 2011; Kellis & Katis, 2007b).

Despite the lack of clarity associated with isokinetic strength and kicking performance, several studies have instead examined whether functionally based strength and conditioning interventions are able to optimise foot velocity production as a mechanism to enhance kicking distance and kicking performance (Billot, Martin, Paizis, Cometti & Babault, 2010; Campo et al, 2009; Perez-Gomez et al, 2008a; Ball, 2007b; Vucetic, Sporis & Jukic, 2007; Manolopoulos et al, 2006; Manolopoulos et al, 2004; Young et al, 2004; Aagaard et al, 1996). While earlier studies demonstrated no gains in kicking performance following single-joint strength training interventions (Aagaard et al, 1996; Aagaard et al, 1994), the overriding conclusion drawn from a multitude of more recent studies demonstrate significant improvements in kicking distance in response to multi-joint, dynamic, heavy-resistance and plyometric based training activities (Billot et al, 2010; Campo et al, 2009; Perez-Gomez et al, 2008; Manolopoulos et al, 2004).

Furthermore, when combining skill-based kicking practice concurrently with resistance training interventions, even larger kicking performance improvements are evident (Young & Rath, 2011; Ball 2007b; Manolopoulos et al, 2006), likely in response to an element of motor learning transference experienced between skill-based training, and subsequent resistance based strength gains (Young, 2006; Davids et al, 2000). This presents a novel, and interesting concept for further research efforts, particularly aiming to further understanding the impact of concurrent skill acquisition and resistance training programs on the subsequent enhancement and modification of kicking performance, and the manner in which these may adjust the biomechanical profile of an athlete when kicking for distance.

2.4.2. Kicking Accuracy

The improvement of kicking accuracy and performance remains one of the basic aims of coaches and athletes in football sports, with considerable time and resources assigned to developing the kicking skill (Kellis & Katis, 2007a; Dichiera et al, 2006). In particular, the act of kicking a ball accurately to a specified target could arguably be the most important skill to master (Ball, 2007b), as the effectiveness of a single kick can often differentiate between winning or losing a competitive match (Ball, 2007a; Dichiera et al, 2006). Therefore any kicker who is able to deliver a ball accurately, over greater maximal and sub-maximal distances becomes a more critical asset to their team (Young & Rath, 2011; Young et al, 2010; Ball, 2008; Dichiera et al, 2006). Despite the importance of kicking accuracy in sport, research investigating ways to describe, develop and improve this technical characteristic remains highly limited (Young et al, 2010; Sterzing et al, 2009; Dichiera et al, 2006).

Only one study to date has attempted to describe the kinematic strategy employed by accurate kickers in comparison to inaccurate kickers, identifying evident differences in lower limb characteristics (Dichiera et al, 2006). In particular, accurate kickers were able to achieve greater hip and knee flexion angles in the support leg during the support phase of the kicking motion, while also producing greater anterior pelvic tilt at the moment of weight acceptance (Dichiera et al, 2006). The functional benefits of these characteristics are two-fold: 1) increased flexion of the hip and knee in the support leg enables accurate kickers to effectively adjust and lower their centre of gravity to increase or maintain athletic stability during the kicking task (Dichiera et al, 2006; Rahnama et al, 2005); and 2) greater anterior pelvic tilt invokes a greater stretch on the trunk and hip flexor muscles during the backswing of the kick (Hosford & Meikle, 2007; Orchard et al, 1999), subsequently resulting in less volitional effort to generate an equivalent limb velocity required to reach the target, which might increase limb control and position while in contact with the ball (Cameron & Adams, 2003).

In the absence of sufficient biomechanical outcomes relevant to the production of kicking accuracy, there appear to be several studies which have examined the physiological influence of acute and longer-term fatigued states on the subsequent generation of kicking accuracy and kicking technique (Coventry et al, 2011; Young et al, 2010; Kellis, Katis & Vrabas, 2006; McMorris, Gibbs, Palmer, Payne & Torpey, 1994). While acute fatigue appears to facilitate kicking accuracy in response to a proposed heightening of arousal levels (Young et al, 2010; Royal et al, 2006; Lyons, Al-Nakeeb & Nevill, 2006), longer-term fatigued states appear to considerably diminish and impair kicking accuracy, creating a breakdown in technique, and an increase in relative muscular exertion (Coventry et al, 2011; Kellis et al, 2006; Lyons et al, 2006; McMorris et al, 1994). Since football matches often entail continual bouts of repeated high intensity activities over prolonged durations (Coventry et al, 2011; Wisbey, Montgomery, Pyne & Rattray, 2010; Young et al, 2010), it would appear more probable that kicking accuracy would be further hampered by fatigue as games progress into later stages, however, an interaction between higher levels of endurance-based fitness and improved tolerance to physiological game-based stress has been shown (Young et al, 2010), implicating fitness as a key component to protect against skill impairment, however further research is necessary.

Despite the positive influence of strength and conditioning programs on the production and enhancement of kicking distance (Young & Rath, 2011), there appear to be no studies in the literature examining the ways in which strength and conditioning interventions might be-able to facilitate and improve kicking accuracy. This seems rather counterintuitive considering the obvious importance of kicking accuracy in football sports, which are entirely reliant on efficient ball progression and frequent scoring sequences to generate successful game-based outcomes. In particular, modifying the quantity and quality of body mass within an athlete can have a profound impact on the subsequent strength levels and biomechanical strategies used to generate successful performances (Malina & Geithner, 2011; Nevill et al, 2009; Jones, Bishop, Woods & Green, 2008; Perez-Gomez et al, 2008b; Gissis et al, 2006; Loucks, 2004), and may potentially be-able to positively influence kicking accuracy in football sports.

For example, increasing the overall mass of the kicking leg should enable an equivalent distance to be achieved at a proportionately lower foot velocity. As motor control theory promotes an evident trade-off between speed of movement and accuracy outcomes (Nagengast, Braun & Wolpert, 2011; Beilock, Bertenthal, Hoeger & Carr, 2008; Magill, 2008), this might be one potential method to increase kicking accuracy. Another example might include increasing the overall mass of the support leg, as this might heighten athletic stability during the dynamic unipedal task of kicking (Burkett, 2010; Dichiera et al, 2006; Paillard et al, 2006), which could also increase the likelihood of accurate outcomes. Lastly, increasing the quantity of lean mass and lower limb strength might enable a reduced mechanical effort for a given distance; honouring the theory of impulse-variability by utilising less percentage of the motor unit pool and lower relative muscular impulses to achieve greater limb control (Urbin et al, 2011; Schmidt & Lee, 2005) and therefore may potentially improve kicking accuracy. These examples provide only a basic insight into the many possible benefits resistance training may provide to enhance kicking performance, highlighting the need for further research and comprehensive investigation in this area.

2.6. Summary

The kicking action is a defining skill in football sports (Lees et al, 2010; Ball, 2011; Sterzing & Hennig, 2008). Therefore, the ability to kick accurately over longer distances to intended targets is highly desirable, however, few scientific investigations have described the whole-body interactions of the skill, or the manner in which physiological, strength-based, or skill-based interventions may optimise performance.

This literature review has identified many potential areas of interest for future researchers and practitioners alike, specifically concerning the kicking landscape, with a focus on the drop punt kick. In particular, few formal scientific analyses have been produced to investigate whole-body three-dimensional biomechanical interactions, including the behaviour of the upper body (head, trunk, ipsilateral arm and contralateral arm); movement co-ordination of upper body segments concurrently with lower body segments; contributions of the support leg to foot velocity production and athletic stabilisation; ball drop and contact characteristics; as well as the inherent differences between these interactions when accounting for skill level, technical proficiency, or performance outcomes. For example, biomechanical strategies when kicking for distance will differ from such strategies when kicking for accuracy. In addition, biomechanical strategies when kicking at player targets will differ from adopted strategies when kicking at goals targets; even though both requirements have accuracy constraints, and these also require due consideration.

An evident theme within this literature review illustrates a great lack of understanding as to how physical conditioning practices influence kicking performance. While there is an evident role for strength and power training towards the generation of kicking distance, there is a notable absence of research investigating the manner in which the strength and muscularity profiles of athletes might influence kicking accuracy. The focus of this thesis aims to extend the knowledge in this particular area, as a tool to see whether strength and muscularity profiles of athletes can have positive outcomes for kicking performance, which may lay the foundation for future longitudinal, intervention based studies.

CHAPTER THREE – STUDY ONE

A STANDARDISED IN-VIVO METHOD TO IDENTIFY AND ASSESS APPENDICULAR SEGMENTAL MASS USING DUAL ENERGY X-RAY ABSORPTIOMETRY (DEXA).

SPORTS BIOMECHANICS
(IN REVIEW, JANUARY 2012).

Nicolas H. Hart, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton

3.0. Abstract

The popularity of DEXA has intensified in recent times, becoming a mainstream tool used to accurately and reliably determine body segment parameters and body composition components. While whole body scan models separate the body into axial and appendicular regions, there is a need for a standardised appendicular model to further segmentate the upper and lower extremities. This paper provides a method with clear and transparent subject positioning guidelines; a standardised appendicular segmentation model; and clear post-processing regional analysis procedures. To assess methodological reliability, whole body scans were performed on 15 professional football athletes (age: 21.1 ± 3.3 years; mass: 80.6 ± 8.3 kg; height: 1.81 ± 0.07 m; BMI: 24.4 ± 1.3), with all scans analysed twice by the main investigator on separate days, and by a second investigator a week following the original analysis. The method presented in this study produced very high intra-tester reliability (CV ≤ 2.6%; ICC ≥ 0.941) and very high inter-tester reliability (CV ≤ 2.4%; ICC ≥ 0.961), demonstrating very high methodological reproducibility within and between researchers. It is therefore strongly recommended that future studies using DEXA technology to determine body segment parameters and body composition components utilise the methodological procedure outlined in this paper.

3.1. Introduction

The accuracy of biomechanical models and human movement data largely relies on obtained mechanical values to estimate and replicate the true anatomical structure of its subjects (Durkin, Dowling & Andrews, 2002; Lee, Koh, Fang, Le & Balasekaran, 2009a; Pearsall & Costigan, 1999; Pearsall & Reid, 1994; Rao, Amarantini, Berton & Favier, 2006). In particular, body segment parameters and body composition components provide important data for biomechanists and exercise physiologists in the analysis of human movement and health status in both sporting and clinical contexts (Dumas, Cheze & Verriest, 2007; Lee et al., 2009a; Peiffer et al., 2010; Pearsall & Reid, 1994; Rao et al., 2006). More specifically, segmental anthropometric parameters are routinely estimated for use within inverse dynamics equations in order to calculate intersegmental forces and net joint moments during gait, kicking, throwing and striking actions (Davids, Lees & Burwitz, 2000; Ganley & Powers, 2004a; Ganley & Powers, 2004b; Lee, Le, Fang & Koh, 2009b; Pearsall & Costigan, 1999; Putnam, 1993; Putnam, 1991; Rao et al., 2006), while composite mass assessments are used to diagnose and monitor health status and changes in paediatric, athletic, adult and geriatric populations (Abrahamyan, Gazarian & Braillon, 2008; Beaumesnil et al, 2011; Bridge et al, 2009; Fawzy et al, 2011; Miller et al, 2009; Peiffer et al., 2010; Veale, Pearce, Buttifant & Carlson, 2010).

Body segment parameters, including segmental mass, length, centroids and moments of inertia (Durkin et al., 2002; Lee et al., 2009a); have historically been generated from predictive linear and non-linear equations obtained from human cadavers (de Leva, 1996; Dumas et al., 2007; Hinrichs, 1990; Hinrichs, 1985; McConville, Churchill, Kaleps, Clauser & Cuzzi, 1980). However, these measures are limited by assumptions of mass uniformity amongst all subject populations (Dumas et al., 2007; Durkin et al., 2002; Reid & Jensen, 1990), providing a distinct lack of external validity (Pearsall & Reid, 1994), thus prompting researchers to seek more pragmatic and accurate methods of determining body segment parameters and body composition components within living humans (Mungiole & Martin, 1990).

Advancements in technology have enabled scientists to investigate modern in-vivo techniques, such as magnetic resonance imaging (Bridge et al., 2009; Martin, Mungiole, Marzke & Longhill, 1989; Mungoile & Martin, 1990; Pearsall, Reid & Ross, 1994), computed tomography imaging (Huang & Suarez, 1983; Huang & Wu, 1976; Pearsall, Reid & Livingston, 1996), stereo-photogrammetry (Ackland, Blanksby & Bloomfield, 1988; Jensen, 1986; Jensen, 1978), gamma-mass scanning (Zatsiorsky & Seluyanov, 1985) and ultrasound (Lee et al., 2009a; Milburn, 1991). While these measures provide accurate representations of body segment parameters and body composition components (Durkin et al., 2002), the inherent radiation, cost, time commitment and scarce availability of equipment has limited the practicality and industry support of such measurement techniques (Martin et al., 1989; Pearsall & Reid, 1994). This highlights the need for safer, more time-efficient and cost-effective assessment tools (Durkin et al., 2002; Peiffer et al., 2010).

In recent times, a two-dimensional in-vivo imaging technique known as dual energy x-ray absorptiometry (DEXA) has been used to capture full body projections of mass densities through x-ray technology (Durkin et al., 2002; Peiffer et al., 2010). In comparison with previous imaging techniques, it is inexpensive, exposes the participant to substantially less radiation, is widely available for use, and produces less than 3.2% error when employed to ascertain body segment parameter measures (Durkin & Dowling, 2006; Heymsfield et al., 1990; Lee et al., 2009a; Pietrobelli, Formica, Wang & Heymsfield, 1996). Dual energy x-ray absorptiometry functions by emitting two collimated x-ray beams of alternating frequencies that passes through the individual being scanned (Durkin et al., 2002; Hologic, 2004). The resulting attenuation coefficients are used within a two-compartment model to differentiate between bone, fat and lean tissue mass (Ganley & Powers, 2004a; Ganley & Powers, 2001; Pietrobelli et al., 1996). On completion, the scan creates a pixel-by-pixel, two-dimensional reconstruction of the subject allowing regional analysis to be performed (Lee et al., 2009b; Ganley & Powers, 2004b).

Presently, full body scans utilise mandatory predefined regions as per a standardised whole body model which separates the subject into axial and appendicular sections (Durkin et al., 2002; Heymsfield et al., 1990). This provides useful information when assessing the whole body in its entirety. However, the determination of body segment parameters and localised composite measures requires more specific regions to be identified (Lee et al., 2009a; Ganley & Powers, 2004a). In particular, there is a need for further segmentation of the upper and lower extremities of the appendicular skeleton to differentiate the upper arm, forearm, hand, thigh, shank and foot segments. Due to DEXA's capability to accurately quantify the mass of defined regions (Glickman, Marn, Supiano & Dengel, 2004; Haarbo, Gotfredsen, Hassager & Christiansen, 1991; Kohrt, 1998; Lee et al., 2009b), it is the two-fold purpose of this paper to: 1) present a standardised methodological approach to assess and analyse in-vivo appendicular segmental mass; and 2) determine the between-day intra-tester and inter-tester reliability of the proposed regional boundaries and segmental cross-sections using DEXA technology.

3.2. Methods

3.2.1. Subjects

Fifteen professional football athletes (age: 21.1 ± 3.3 years; mass: 80.6 ± 8.3 kg; height: 1.81 ± 0.07 m; BMI: 24.4 ± 1.3) were recruited for participation in this study, with specific segmental mass characteristics provided in Table 1. All subjects were absent of injury and contraindication, and were required to wear clothing free of metallic material. Ethics approval was obtained from the human research ethics committee of Edith Cowan University. Subjects were notified of potential risks, and provided written informed consent. Standing height was recorded to the nearest 0.1 centimetre using a wall-mounted stadiometer, with body mass recorded to the nearest 0.1 kilogram using a standard electronic weighing scale.

3.2.2 Scan Procedure

Whole body scans were performed using dual energy x-ray absorptiometry (DEXA, QDR-1500; Hologic Discovery A, Waltham, MA) in order to determine the magnitude and quality of full body mass distribution (fat, lean and total). In accordance with body positioning instructions outlined by Hologic's whole body model (Hologic, 2004), subjects assumed a stationary, supine position on the scanning bed with both arms pronated by their side, and hands facing the table. To ensure consistent and reproducible body positioning, the DEXA operator manually assisted subjects in order to straighten their head, torso and pelvis; internally rotate and fixate their legs and feet at 45°; and position their arms next to the body within the DEXA scanning zone (Figure 1). This has been shown to produce a scan/re-scan coefficient of variation below 1% in our laboratory for body composition components (Peiffer et al., 2010).

Table 1. Subject characteristics of appendicular segmental mass for the upper and lower limbs

	LEFT SEGMENTS			
	Upper Arm	Forearm	Hand	Whole Arm
Lean (g)	2855.7 ± 354.6	1153.0 ± 99.0	416.8 ± 36.1	4425.5 ± 465.3
Fat (g)	338.6 ± 83.9	110.7 ± 22.2	49.9 ± 16.5	499.2 ± 112.3
Total (g)	3194.3 ± 414.0	1263.6 ± 113.2	466.7 ± 44.1	4924.6 ± 542.8
	Thigh	Shank	Foot	Whole Leg
Lean (g)	8141.7 ± 990.6	2971.9 ± 259.8	818.3 ± 113.6	11931.9 ± 1221.9
Fat (g)	1156.3 ± 369.6	362.4 ± 126.4	120.3 ± 63.3	1639.0 ± 508.2
Total (g)	9298.0 ± 1243.8	3334.4 ± 333.1	938.6 ± 97.2	13571.0 ± 1558.4
	RIGHT SEGMENTS			
	Upper Arm	Forearm	Hand	Whole Arm
Lean (g)	3064.9 ± 376.6	1203.1 ± 98.4	407.4 ± 46.5	4675.4 ± 471.8
Fat (g)	355.0 ± 77.9	114.3 ± 25.9	69.2 ± 26.7	538.5 ± 104.2
Total (g)	3419.9 ± 432.5	1317.3 ± 117.0	476.6 ± 46.9	5213.9 ± 548.0
	Thigh	Shank	Foot	Whole Leg
Lean (g)	8200.7 ± 924.2	2946.1 ± 292.2	794.8 ± 138.2	11941.6 ± 1180.6
Fat (g)	1175.1 ± 380.4	403.8 ± 97.0	161.3 ± 99.4	1740.2 ± 511.0
Total (g)	9375.9 ± 1205.3	3349.9 ± 354.6	956.1 ± 100.8	13681.8 ± 1565.5

Note: Values are expressed as mean ± *SD*.

Figure 1. A frontal and side view of correct subject positioning on the scan bed, showing the positioning device used to internally rotate each thigh.

3.2.3. Scan Analysis

Using the in-built scan analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, MA), the scanned full body images were separated into eighteen segments. Six segments were predefined by Hologic's standard whole body model (Table 2), as the head, trunk, left arm, right arm, left leg and right leg regions, as illustrated in Figure 2a. Eight segments were created using the sub-region analysis tool in order to further define the left forearm, left hand, right forearm, right hand, left shank, left foot, right shank and right foot regions as outlined in Table 3. The remaining four segments, defined as the left upper arm, left thigh, right upper arm and right thigh regions were then determined using the residual segments located between the proximal boundary of the entire limb defined by the whole body model, and the proximal boundary of the distal segments defined sub-region analysis as seen in Figures 2b and 2c. The anatomical boundaries used for these newly created sub-regions were developed in conjunction with Dempster's body segment parameter boundaries for 2D studies (Winter, 1990).

Table 2. Standard whole-body cross-sections as defined by Hologic's whole body model (Hologic, 2004).

Region	Anatomical Cross-sections	Direction of line	Number of lines
Head	Base of Mandible (cervical region)	Horizontal	1
Trunk	Peak of Iliac Crest (lumbar region)	Horizontal	1
Spine	Lateral boundaries of vertebrae	Vertical	2
Arms	Glenohumeral Joint	Diagonal	2
Legs [a]	Femoral Neck [a]	Diagonal	2

[a] Mass of pelvis is not included

Table 3. Proposed appendicular cross-sections for each segment, with proximal and distal boundaries and descriptive landmarks.

Segment / Region	Proximal boundary	Distal boundary	Basic description [a]
Upper Arm	Glenohumeral Joint	Humeroulnar Joint	Commences between the head of the Humerus and glenoid fossa of the Scapula, separating the upper arm from the trunk; Ending at the elbow axis, noted by the trochlea of the Humerus and olecranon process of the Ulna.
Forearm	Humeroulnar Joint	Ulnocarpal Joint	Commences at the elbow axis (described above); Ending through the wrist axis, noted by the styloid process of the Ulna, and the base of the Pisiform, Lunate and Scaphoid carpal bones.
Hand	Ulnocarpal Joint	Distal Phalanges	Commences through the wrist axis (described above); Ending at the most distal point of the phalanges of the hand.
Thigh [b]	Femoral Neck [b]	Tibiofemoral Joint	Commences superior to the greater trochanter of the Femur, crossing the femoral neck, separating the thigh from the pelvis; Ending through knee axis, noted as the 'tibial plateau' (space between the femoral and tibial condyles).
Shank	Tibiofemoral Joint	Talocrural Joint	Commences through the knee axis (described above); Ending through the ankle junction, noted as the articulation between the Talus, Tibia and Fibula, spanning beneath the medial and lateral malleoli.
Foot	Talocrural Joint	Distal Phalanges	Commences through the ankle junction (described above); Ending at the most distal point of the phalanges of the foot.

[a] Further boundary description and instruction is provided in Section 2.3.1 and Section 2.3.2
[b] Mass of pelvis is not included

3.2.3.1. Whole Body Model

Scan analysis commences by applying the mandatory, predefined whole body model as required for the scan analysis software (Hologic, 2004). This is achieved by adjusting the pre-supplied zones on the scan image (Figure 2a) to accurately separate the axial skeleton from the appendicular skeleton as per details provided in Table 2. In particular, the whole body model separates the head, arms and legs from the trunk; while also isolating the spine and pelvis as separate entities. Of importance to the appendicular model, is the separation of the arms and legs from the trunk at their most proximal points; the glenohumeral joint and femoral neck respectively, as this has subsequent implications for segmental analysis.

3.2.3.2. Appendicular Model.

The upper and lower extremities can each be separated into three key segments. Using the sub-region analysis tool in conjunction with the previously defined extremities in the whole body model, these segments can easily be assessed. Using a distal-to-proximal approach, sub-regions should be created to separate and capture the forearms, hands, shanks and feet of the extremities, totalling eight sub-regions (see Figure 2b for an example). The upper arm and thigh segments do not require their own sub-regions as these segments are able to be represented by the residual regions of mass which are yet to be specifically defined by either whole body or sub-region boundaries (Figure 2b).

Therefore, in order to calculate the upper arm region, the summation of composite mass of the forearm and hand (assessed using sub-regions) can be deducted from the whole arm (assessed using the whole body model): Upper arm = total arm – [forearm + hand]. Using the example data provided in Table 4, the total mass of the right upper arm would equate to

2827.3 grams, calculated as: 4554.4 – [1232.8 + 494.3]. Similarly, the thigh region is also calculated by using the same process; deducting the summation of the shank and foot mass, from the whole leg: Thigh = total leg – [shank + foot]. Using the example data provided in Figure 3, the total mass of the left thigh would equate to 7946.5 grams, calculated as: 12183.3 – [3291.1 + 945.7]. While the researcher may opt to specifically create new sub-regions to define the upper arms and thighs using the specifications in Table 3, the process itself is not a requirement of the appendicular model.

3.2.4. Sub-region Creation

During the sub-region creation and positioning process, zones can be repositioned and manipulated by modifying the line length, angle and location of boundaries; providing investigators with full sub-region customisation. Therefore, when adjusting the proximal and distal boundaries of a sub-region, consideration must be given to the manner in which the line crosses the specified joint. In particular, the boundary line must: 1) dissect the joint at its centre, 2) capture all bones within the segment, and 3) not encroach on other sub-regions. This means the line is positioned at the point of articulation, and is angled to correspond with the most medial and lateral limits of the articulation. Additionally, the proximal boundary of the distal segment must be drawn to commence at the same location as the distal boundary of the proximal segment, specific to line direction, length and angle (Figure 2b). These factors are important as composite mass is assigned to the scan image on a pixel-by-pixel basis (Lee et al., 2009b; Ganley and Powers, 2004b). This enables the prevention of regional loss or overlap, protecting against inflated or deflated segment outputs, while enabling consistent standards for analysis across scans (Dumas et al., 2007).

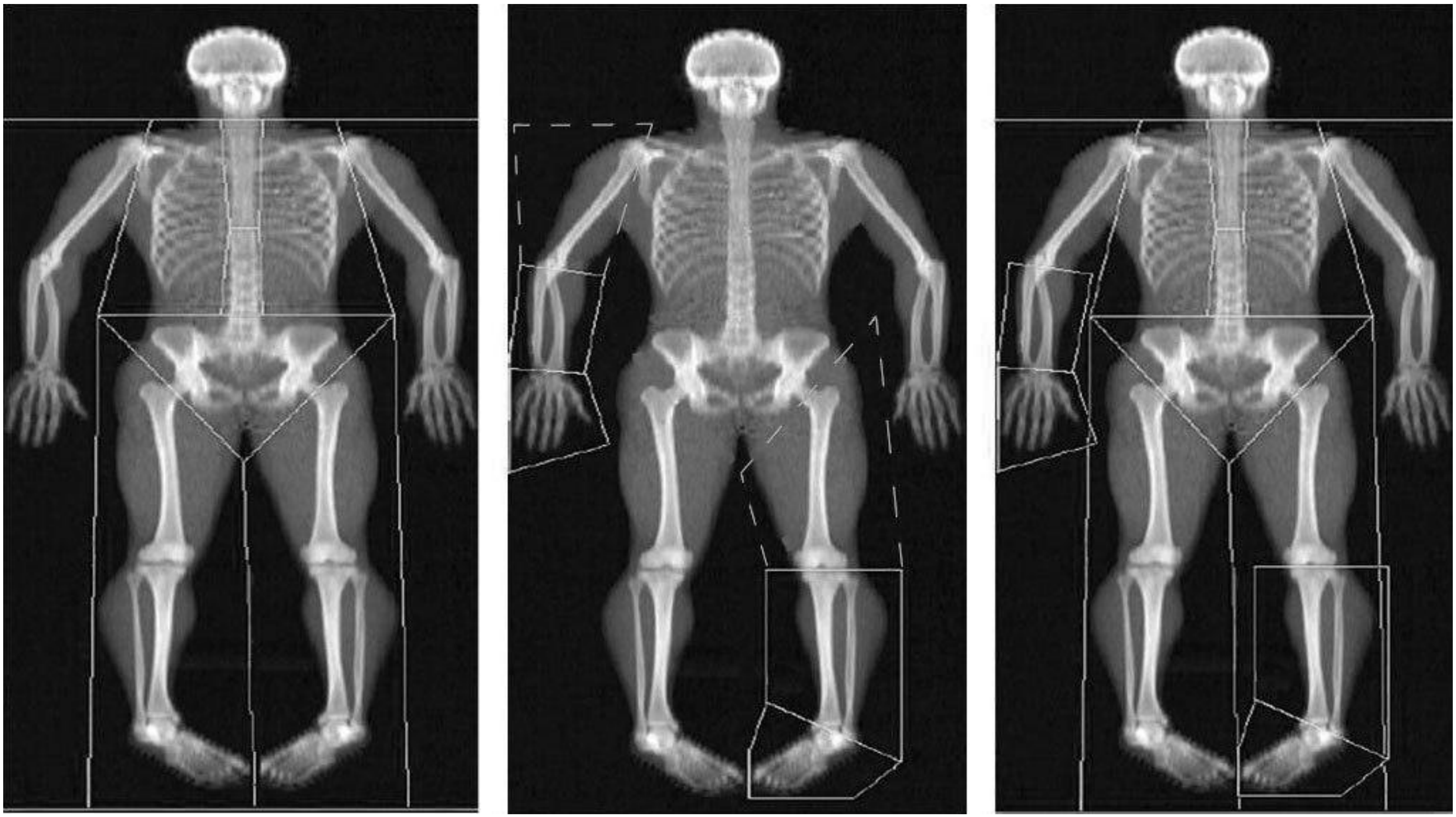


Figure 2. Illustrations of applied (a) whole body scan regions, (b) proposed appendicular sub-regions; and (c) the resultant combined scan image produced during analysis.

Table 4. Example results provided by DEXA, showing the whole body model outputs (top) and appendicular model outputs (bottom).

Region	**BMC (g)**	**Fat (g)**	**Lean (g)**	**Lean+BMC (g)**	**Total Mass (g)**	**% Fat**
L Arm	196.76	389.9	3698.9	3895.6	4285.5	9.1
R Arm	212.82	442.6	3899.0	4111.8	4554.4	9.7
Trunk	794.67	1991.1	28261.0	29055.7	31046.8	6.4
L Leg	542.09	1104.0	10537.2	11079.3	12183.3	9.1
R Leg	533.86	1103.9	10877.4	11411.3	12515.2	8.8
Subtotal	2280.20	5031.4	57273.5	59553.7	64585.2	7.8
Head	424.96	890.2	3134.6	3559.5	4449.8	20.0
TOTAL	**2705.16**	**5921.7**	**60408.1**	**63113.2**	**69034.9**	**8.6**
Sub-Region	**BMC (g)**	**Fat (g)**	**Lean (g)**	**Lean+BMC (g)**	**Total Mass (g)**	**% Fat**
L Shank	221.45	360.4	2709.3	2930.7	3291.1	11.0
R Farm	71.89	80.7	1080.2	1152.1	1232.8	6.5
L Foot	68.32	77.6	799.8	868.1	945.7	8.2
R Hand	28.26	116.8	349.3	377.6	494.3	23.6
TOTAL	**386.67**	**634.4**	**4929.9**	**5316.6**	**5951.0**	**10.7**

All fifteen scans were analysed twice by the same investigator on separate days, and were re-analysed by a second investigator a week following the initial analysis. All investigators were required to follow the sub-region analysis method described above in order to assess the between-day intra-tester and inter-tester reliability for the newly created appendicular sub-regions.

3.2.5. Statistical Analysis

Body composition outputs were categorised into fat mass (g), lean mass (g) and total mass (g) values for each of the proposed sub-regions for all scans and subjects using Microsoft Excel (Microsoft, Redmond, WA). Between day intra-tester and inter-tester reliability were assessed by calculating the coefficient of variation (CV) and intraclass correlation coefficient (ICC) using a statistical analysis package (SPSS, Version 17.0; Chicago, IL). The strength of relationship for ICC coefficients was classified in accordance with Hopkins (2002): $r \pm 0.3$ is moderate; $r \pm 0.5$ is strong; $r \pm 0.7$ is very strong; $r \pm 0.9$ is nearly perfect; and $r \pm 1.0$ is perfect. Coefficients of variation below 5% ($CV \leq 5\%$) are considered highly reliable, as described by Hopkins (2002; 2000).

3.3. Results

3.3.1. Intra-tester Reliability

Reliability statistics for between day, intra-tester scan analysis across all appendicular segments are presented in Table 5. Between day, sub-region processing / re-processing reliability for all body composition components was very high, with all CV percentages below 2.6%, 2.3% and 2.3% for fat, lean and total mass respectively, between appendicular segments on both dominant and non-dominant limbs. Nearly perfect intra-tester reliability was additionally confirmed with ICC figures all above 0.993, 0.941 and 0.949 for fat, lean and total mass respectively.

3.3.2. Inter-tester Reliability

Reliability statistics for inter-tester analysis are presented in Table 6. Sub-region processing reliability between testers for all body composition components was very high with all CV percentages below 2.4%, 2.3% and 2.3% for fat, lean and total mass respectively. Nearly perfect inter-tester reliability was additionally confirmed with all ICC figures above 0.994, 0.947 and 0.961 for fat, lean and total mass components respectively. This demonstrates high levels of reproducibility between testers.

Table 5. Intra-tester, between day reliability coefficients for all newly created sub-region segments of the appendicular skeleton across all composite mass outputs.

Region	**Fat (g)**		**Lean (g)**		**Total (g)**	
	CV (%)	ICC (R)	CV (%)	ICC (R)	CV (%)	ICC (R)
Left Forearm	1.6	0.994	1.5	0.971	1.7	0.967
Left Hand	1.5	0.998	1.5	0.970	1.5	0.996
Right Forearm	2.1	0.993	2.1	0.941	2.2	0.949
Right Hand	2.6	0.996	2.3	0.957	2.3	0.956
Left Shank	1.5	0.998	0.8	0.992	0.9	0.993
Left Foot	2.2	0.997	1.5	0.990	1.4	0.982
Right Shank	1.2	0.998	0.8	0.993	0.8	0.994
Right Foot	1.5	0.999	1.9	0.989	1.8	0.972

Table 6. Inter-tester reliability coefficients for all newly created sub-region segments of the appendicular skeleton across all composite mass outputs.

Region	**Fat (g)**		**Lean (g)**		**Total (g)**	
	CV (%)	ICC (R)	CV (%)	ICC (R)	CV (%)	ICC (R)
Left Forearm	2.2	0.994	2.2	0.947	2.3	0.973
Left Hand	2.4	0.997	2.3	0.952	2.2	0.961
Right Forearm	1.6	0.996	1.5	0.974	1.5	0.977
Right Hand	1.9	0.998	1.7	0.978	1.7	0.967
Left Shank	0.5	1.000	0.5	0.997	0.5	0.997
Left Foot	2.1	0.997	1.7	0.986	1.8	0.974
Right Shank	1.1	0.998	0.7	0.995	0.9	0.996
Right Foot	1.3	0.996	1.8	0.983	1.7	0.979

3.4. Discussion

Despite biomechanical and physiological relevance, precise quantifications of segmental inertial properties and composite measures of the appendicular skeleton remain largely inadequate (Durkin & Dowling, 2006; Heymsfield et al., 1990; Wells, 2009). While current in-vivo techniques provide broad insight into axial and appendicular regions (Fuller, Laskey & Elia, 1992; Heysmfield et al., 1990; Visser, Fuerst, Lang, Salamone & Harris, 1999), no definitive boundaries have been reliably described and validated to further distinguish between individual segments of the upper and lower extremities using scan technology. Several authors have used dual energy x-ray absorptiometry to further define appendicular segments (Durkin & Dowling, 2006; Ganley & Powers, 2004a; Ganley &

Powers, 2004b; Lee et al., 2009a; Lee et al., 2009b; Visier et al., 1999), however, concerning methodological inconsistencies exist in the literature pertaining to exact subject positioning and segmental boundaries employed during the scan completion and analysis process.

To address this notable deficiency, the aim of this study was: 1) to propose a standardised methodological approach to assess and analyse in-vivo appendicular segmental mass; and 2) to determine the between-day intra-tester and inter-tester reliability of our proposed segmental cross-sections. When adopting the subject positioning and regional analysis procedures outlined in our methodology, the results of this study demonstrate very high reliability. In particular, the scan-rescan coefficient of variation (CV) for the subject positioning protocol used for this study has routinely produced a score below 1% (Peiffer et al, 2010), with intra-tester and inter-tester CV scores all valued below 3% and ICC scores all above 0.941; well within acceptable limits (Hopkins, 2002). The presented method of this study therefore responds to the need for greater methodological reproducibility, transparency and consistency to ensure that reported values are truly comparable between research (Hopkins, 2000), particularly as body segment parameters obtained using DEXA technology can be used within biomechanical models that are potentially sensitive to data input fluctuations (Ganley & Powers, 2004a; Lee et al., 2009b; Lenzi et al., 2003; Pearsall & Costigan, 1999; Rao et al., 2005).

To date, previous research has employed a variety of different subject positioning protocols when using DEXA for whole body scans. While subjects in all studies have adopted lying, supine positions, there is a lack of consistency within the literature regarding the selected positioning of upper and lower extremities (Table 7). This creates a specific problem when using DEXA, as the measurement process is only able to directly quantify fat and fat-free mass where bone is not present (Wells, 2009), relying on estimation equations to indirectly fulfil the remaining composition parameters (Pietrobelli et al., 1999; Wells, 2009). As a result, the precise frontal plane surface area of the upper and lower extremities becomes critically important to the DEXA operator, and the subsequent accuracy of data outputs.

Currently only two studies assessing appendicular segmental mass have described their upper extremity positioning protocol (Durkin & Dowling, 2003; Durkin & Dowling, 2002), placing their subject's arms by their side, in pronation, with their hands facing the scanning bed. This is in agreement with the proposed methodology of this paper. However, precise descriptions of lower extremity positioning are equally as scarce and conflicting. Ganley and Powers (2004a; 2004b) placed both legs into external rotation with feet in maximal plantarflexion; Durkin and Dowling (2006) positioned both legs neutrally with feet in slight dorsiflexion; while Lee and colleagues (2009a; 2009b) presented scan images showing internal rotation of both legs with neutral foot position; and several authors did not disclose or demonstrate any subject positioning procedures used within their studies (Table 7). This increases the likelihood of positional discrepancies amongst research in this area. Positioning of the lower extremities reported in, and recommended by this study is in agreement with that used by Lee and colleagues (2009a; 2009b).

Table 7. Review and comparison of subject positioning, segment boundaries, and reliability data between studies determining appendicular segments using DEXA technology.

Author(s)	Year	Subject Positioning	Segment Boundaries	Reliability
Lee & colleagues	2009b	Lying, supine position. No upper or lower limb position specifications were provided.	Segmental boundaries for upper and lower body segments were used. No anatomical descriptions were provided. A scan image with segmentation locations was supplied.	No reliability data was reported in this paper.
Lee & colleagues	2009a	Lying, supine position. No upper or lower limb position specifications were provided.	Segmental boundaries for upper and lower body segments were used. No anatomical descriptions were provided. A scan image with segmentation locations was supplied.	No reliability data was reported in this paper.
Durkin & Dowling	2006	Lying, supine position with knees extended, and feet in slight dorsiflexion. No upper limb specifications provided.	Shank segmental boundaries used, as described by Durkin & Dowling (2003).	No reliability data was reported in this paper.
Ganley & Powers	2004b	Same procedures as described in Ganley & Powers (2004a).	Lower limb segmental boundaries (Thigh, Shank, Foot), as described by Dempster [b]	No reliability data reported. This study used methods determined as reliable in Ganley & Powers (2004a).

Ganley & Powers	2004a	Lying, supine with lower extremities in external rotation and maximum plantarflexion. No upper limb specifications were provided.	Lower limb segmental boundaries (Thigh, Shank, Foot), as described by Dempster [b]	Between-day scan analysis on five scans, producing a CV range of 0.4% to 6.0%, with a mean CV score of 2.0%.
Durkin & Dowling	2003	Lying, supine, with palms facing the table. No lower limb specifications provided.	Upper limb (Forearm, Hand) and lower limb (Thigh, Shank, Foot) segmental boundaries were described using customised anatomical landmarks to segment regions.	No reliability data was reported in this paper.
Durkin & Dowling	2002	Lying, supine, with forearms pronated, palms facing table. No lower limb specifications were provided.	No specific description or reference to identify segmental boundaries used.	No reliability data was reported in this paper.
Ganley & Powers	2001 [a]	No subject positioning details were reported in this abstract.	Lower limb segmental boundaries (Thigh, Shank, Foot), as described by Dempster [b]	No reliability data was reported in this abstract.
Visser & colleagues	1999	No subject positioning details were described in this paper.	Only the whole leg and thigh regions were described, using a horizontal line through the ischial tuberosity, the knee joint, and the ankle joint as anatomical locations for boundary identification.	No reliability data was reported in this paper.

[a] Conference abstract only.
[b] Dempster (1955).

The advantages of internally rotating the thigh whilst maintaining neutral foot position is three-fold: 1) It maximises the available surface area of fat and fat-free mass of the thigh, shank and foot segments in the frontal plane during the scanning process; 2) provides greater visibility of the calcaneus, talocrural joint and associated landmarks (Table 3) to enhance visibility and zoning precision during post-processing regional analysis; and 3) allows the operator to suitably fixate the subjects feet together to prevent unwarranted movement or disruption during the scanning process. As DEXA technology is only capable of measuring uniplanar, two-dimensional projections (Durkin et al., 2002; Durkin and Dowling, 2003; Lee et al., 2009b; Pietrobelli et al., 1996; Wells, 2009); any inconsistencies in subject positioning, or unwarranted movement during the scan will subsequently modify the resultant scan image and data outputs generated, particularly when composite mass has been redistributed, dually effecting post-processing regional analysis.

Post-processing regional analysis is reliant upon, and a product of, subject positioning during the scanning process. As composite mass is assigned to the scanned image on a pixel-by-pixel basis (Ganley & Powers, 2004b; Lee et al., 2009a), it is influenced by the quantity and distribution of mass viewable in the frontal plane (Durkin et al., 2002; Lee et al., 2009b). Regional boundaries are subsequently applied to the resultant two dimensional scan image (Figure 2) in order to define the limits of each area for analysis, as per criteria outlined using predefined whole body models (Hologic, 2004). Presently, no model exists for appendicular segmental analysis of the upper and lower extremities using DEXA technology. Several authors have attempted to differentiate between segments of the extremities using DEXA; however, inconsistencies exist in the literature regarding selected anatomical locations for body segmentation.

While all authors assessing appendicular mass have segmented the lower extremities using varying regional descriptors, only two authors have reported written or graphical upper extremity boundaries (Lee et al, 2009b; Durkin & Dowling, 2003). Ganley and Powers (2004a; 2004b; 2001) defined lower body segmental boundaries using those described by Dempster (1955); Durkin and Dowling (2003; 2006) and Vissier and colleagues (1999) reported their own unique sets of segmental definitions; while Lee and colleagues (2009a; 2009b) provided only graphical image depictions of their regional end-points with no precise anatomical descriptions or landmarks. These differences in methodological reporting (graphical versus written) and segmental zoning between studies identify a notable lack of homogeneity between there precise applications of anatomical cross-sections to scanned images. This further highlights the need for a standardised and established appendicular model. The upper and lower body segmental boundaries recommended within the framework of this study (Figure 2; Table 3) are in agreement with those used by Ganley and Powers (2004a; 2004b; 2001) and Dempster (1955).

While Ganley and Powers (2004a, 2004b, 2001) only applied segmentations to the lower limbs, their use of Dempster's two-dimensional body segment data (Dempster, 1955; Winter, 1990) provides a suitable and stable reference for expansion to the upper body segments. Ganley and Powers (2004a) employment of Dempster's data is supported by their ability to reliably determine lower body segments using DEXA technology, reporting a between-day intra-tester coefficient of variation (CV) ranging between 0.4 - 6.0%, with an average of 2.0%. No other known authors assessing appendicular segmental mass have reported any reliability data of their methods. In agreement with Ganley and Powers

(2004a) reliability data, our proposed upper and lower body segmentation method produced very high between-day reliability within and between researchers (intra-tester and inter-tester) for all upper and lower body segments. The reliability data provided by our methodological process produced an improved CV range between 0.5 – 2.6%, and an intraclass correlation coefficient (ICC) range between 0.941 – 1.000.

Noteworthy points of distinction between this study to prior studies are considerable, and include: a written explanation, graphical illustration and photograph of subject positioning; written descriptions and graphical illustrations of regional boundaries for all upper and lower appendicular sub-regions; and the determination of methodological and researcher reliability for scan analysis procedures. This aims to ensure that all procedures are reproducible and outcomes are comparable across the future research landscape.

In conclusion, this study provides researchers with a standardised, structured, and reliable model to assess in-vivo appendicular segmental mass using DEXA technology. It is recommended that future research using DEXA technology to assess appendicular segments adhere to the guidelines provided in this paper. It is further recommended that future research focus on technological advancements, with a vision towards vertical 3D scanning and shape analysis solutions. This will have greater specificity towards subject mass distribution against gravity in an upright position, and will allow such measures to transcend across more than one plane of vision.

3.5. References

Abrahamyan, D. O., Gazarian, A., & Braillon, P. M. (2008). Estimation of stature and length of limb segments in children and adolescents from whole-body dual-energy X-ray absorptiometry scans. *Pediatric Radiology, 38*(3), 311-315.

Ackland, T. R., Blanksby, B. A., & Bloomfield, J. (1988). Inertial characteristics of adolescent male body segments. *Journal of Biomechanics, 21*(4), 319-327.

Beaumesnil, M., Chaillou, E., Wagner, A. C., Rouquette, A., Audran, M., & Ginies, J. L. (2011). Body composition analysis in patients with cystic fibrosis. Comparison of 3 methods: dual energy x-ray absorptiometry, bioelectrical impedance analysis, and skinfold measurements. *Archives of Paediatrics, 18*(4), 370-375.

Bridge, P., Pocock, N. A., Nguyen, T., Munns, C., Cowell, C. T., & Thompson, M. W. (2009). Prediction of appendicular skeletal and fat mass in children: excellent concordance of dual-energy X-ray absorptiometry and magnetic resonance imaging. *Journal of Pediatric Endocrinology and Metabolism, 22*(9), 795-804.

Davids, K., Lees, A., & Burwitz, L. (2000). Understanding and measuring coordination and control in kicking skills in soccer: Implications for talent identification and skill acquisition. *Journal of Sports Sciences, 18*, 703-714.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230.

Dempster, W. T. (1955). Space requirements of the seated operator. WADC Technical Report (TR-59-159). OH: Wright-Patterson Air Force Base.

Dumas, R., Cheze, L., & Verriest, J. P. (2007). Adjustments to McConville et al. and Young et al. body segment inertial parameters. *Journal of Biomechanics, 40*(3), 543-553.

Durkin, J. L., & Dowling, J. J. (2003). Analysis of body segment parameter differences between four human populations and the estimation errors of four popular mathematical models. *Journal of Biomechanical Engineering, 125*(4), 515-522.

Durkin, J. L., & Dowling, J. J. (2006). Body segment parameter estimation of the human lower leg using an elliptical model with validation from DEXA. *Annals of Biomedical Engineering, 34*(9), 1483-1493.

Durkin, J. L., Dowling, J. J., & Andrews, D. M. (2002). The measurement of body segment inertial parameters using dual energy X-ray absorptiometry. *Journal of Biomechanics, 35*(12), 1575-1580.

Fawzy, T., Muttappallymyalil, J., Sreedharan, J., Ahmed, A., Alshamsi, S. O., Al Ali, M. S., et al. (2011). Association between Body Mass Index and Bone Mineral Density in Patients Referred for Dual-Energy X-Ray Absorptiometry Scan in Ajman, UAE. *Journal of Osteoporosis, 2011*, 1-4.

Fuller, N. J., Laskey, M. A., & Elia, M. (1992). Assessment of the composition of major body regions by dual-energy X-ray absorptiometry (DEXA), with special reference to limb muscle mass. *Clinical Physiology, 12*(3), 253-266.

Ganley, K. J., & Powers, C. M. (2001). The use of dual energy X-ray absorptiometry in determining subject-specific anthropometric measures for kinetic analysis during gait. *Gait and Posture, 13*, 271-272.

Ganley, K. J., & Powers, C. M. (2004a). Anthropometric parameters in children: a comparison of values obtained from dual energy x-ray absorptiometry and cadaver-based estimates. *Gait and Posture, 19*(2), 133-140.

Ganley, K. J., & Powers, C. M. (2004b). Determination of lower extremity anthropometric parameters using dual energy X-ray absorptiometry: the influence on net joint moments during gait. *Clinical Biomechanics, 19*(1), 50-56.

Glickman, S. G., Marn, C. S., Supiano, M. A., & Dengel, D. R. (2004). Validity and reliability of dual-energy X-ray absorptiometry for the assessment of abdominal adiposity. *Journal of Applied Physiology, 97*(2), 509-514.

Haarbo, J., Gotfredsen, A., Hassager, C., & Christiansen, C. (1991). Validation of body composition by dual energy X-ray absorptiometry (DEXA). *Clinical Physiology, 11*(4), 331-341.

Heymsfield, S. B., Smith, R., Aulet, M., Bensen, B., Lichtman, S., Wang, J., et al. (1990). Appendicular skeletal muscle mass: measurement by dual-photon absorptiometry. *American Journal of Clinical Nutrition, 52*(2), 214-218.

Hinrichs, R. N. (1985). Regression equations to predict segmental moments of inertia from anthropometric measurements: an extension of the data of Chandler et al. (1975). *Journal of Biomechanics, 18*(8), 621-624.

Hinrichs, R. N. (1990). Adjustments to the segment center of mass proportions of Clauser et al. (1969). *Journal of Biomechanics, 23*(9), 949-951.

Hologic. (2004). QDR for Windows XP Reference Manual: Hologic Inc.

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1-15.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Huang, H. K., & Suarez, F. R. (1983). Evaluation of cross-sectional geometry and mass density distributions of humans and laboratory animals using computerized tomography. *Journal of Biomechanics, 16*(10), 821-832.

Huang, H. K., & Wu, S. C. (1976). The evaluation of mass densities of human body in vivo from CT scans. *Computers in Biology and Medicine, 6*(4), 337-343

Jensen, R. K. (1978). Estimation of the biomechanical properties of three body types using a photogrammetric method. *Journal of Biomechanics, 11*(8-9), 349-358.

Jensen, R. K. (1986). Body segment mass, radius and radius of gyration proportions of children. *J Biomech, 19*(5), 359-368.

Kohrt, W. M. (1998). Preliminary evidence that DEXA provides an accurate assessment of body composition. *Journal of Applied Physiology, 84*, 372-377.

Lee, M. K., Koh, M., Fang, A. C., Le, S. N., & Balasekaran, G. (2009a). Estimation of Body Segment Parameters Using Dual Energy Absorptiometry and 3-D Exterior Geometry. *13th International Conference on Biomedical Engineering, 23*(5), 1777-1780.

Lee, M. K., Le, N. S., Fang, A. C., & Koh, M. T. (2009b). Measurement of body segment parameters using dual energy X-ray absorptiometry and three-dimensional geometry: an application in gait analysis. *Journal of Biomechanics, 42*(3), 217-222.

Lenzi, D., Cappello, A., & Chiari, L. (2003). Influence of body segment parameters and modeling assumptions on the estimate of center of mass trajectory. *Journal of Biomechanics, 36*(9), 1335-1341.

Martin, P. E., Mungiole, M., Marzke, M. W., & Longhill, J. M. (1989). The use of magnetic resonance imaging for measuring segment inertial properties. *Journal of Biomechanics, 22*(4), 367-376.

McConville, J. T., Churchill, T. D., Kaleps, I., Clauser, C. E., & Cuzzi, J. (1980). Anthropometric relationships of body and body segment moments of inertia. Dayton, Ohio: Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base.

Milburn, P. (1991). Real-time 3-dimensional imaging using ultrasound. *Proceeds of the XIIIth Congress of the International Society of Biomechanics,* 1230-1231

Miller, A., Strauss, B. J., Mol, S., Kyoong, A., Holmes, P. H., Finlay, P., et al. (2009). Dual-energy X-ray absorptiometry is the method of choice to assess body composition in COPD. *Respirology, 14*(3), 411-418.

Mungiole, M., & Martin, P. E. (1990). Estimating segment inertial properties: comparison of magnetic resonance imaging with existing methods. *Journal of Biomechanics, 23*(10), 1039-1046.

Pavol, M. J., Owings, T. M., & Grabiner, M. D. (2002). Body segment inertial parameter estimation for the general population of older adults. *Journal of Biomechanics, 35*(5), 707-712.

Pearsall, D. J., & Costigan, P. A. (1999). The effect of segment parameter error on gait analysis results. *Gait and Posture, 9*(3), 173-183.

Pearsall, D. J., & Reid, J. G. (1994). The study of human body segment parameters in biomechanics. An historical review and current status report. *Sports Medicine, 18*(2), 126-140.

Pearsall, D. J., Reid, J. G., & Livingston, L. A. (1996). Segmental inertial parameters of the human trunk as determined from computed tomography. *Annals of Biomedical Engineering, 24*(2), 198-210.

Pearsall, D. J., Reid, J. G., & Ross, R. (1994). Inertial properties of the human trunk of males determined from magnetic resonance imaging. *Annals of Biomedical Engineering, 22*(6), 692-706.

Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., et al. (2010). Strength and functional characteristics of men and women 65 years and older. *Rejuvenation Research, 13*(1), 75-82.

Pietrobelli, A., Formica, C., Wang, Z., & Heymsfield, S. B. (1996). Dual-energy X-ray absorptiometry body composition model: review of physical concepts. *American Journal of Physiology, 271*(Endocinol. Metab.), E941-951.

Putnam, C. A. (1991). A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Medicine and Science in Sports and Exercise, 23*(1), 130-144.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics, 26* (Suppl. 1), 125-135.

Rao, G., Amarantini, D., Berton, E., & Favier, D. (2006). Influence of body segments' parameters estimation models on inverse dynamics solutions during gait. *Journal of Biomechanics, 39*(8), 1531-1536.

Reid, J. G., & Jensen, R. K. (1990). Human body segment inertia parameters: a survey and status report. *Exercise and Sport Sciences Reviews, 18*, 225-241.

Veale, J. P., Pearce, A. J., Buttifant, D., & Carlson, J. S. (2010). Anthropometric profiling of elite junior and senior Australian football players. *International Journal of Sports Physiology and Performance*, *5*(4), 509-520.

Visser, M., Fuerst, T., Lang, T., Salamone, L., & Harris, T. B. (1999). Validity of fan-beam dual-energy X-ray absorptiometry for measuring fat-free mass and leg muscle mass. Health, Aging, and Body Composition Study--Dual-Energy X-ray Absorptiometry and Body Composition Working Group. *Journal of Applied Physiology*, *87*(4), 1513-1520.

Wells, J. (2009). The limitations of DXA for body composition assessment. *Endocrine Abstracts*, *19*, S78.

Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement* (2nd ed.). Toronto: John Wiley & Sons, Inc.

Zatsiorsky, V. M., & Seluyanov, V. M. (1985). The mass and inertia characteristics of the main segments of the human body. In H. Matsui & K. Kobayashi (Eds.), *Biomechanics VIIIB*. Champaign, IL: Human Kinetics.

CHAPTER FOUR – STUDY TWO

RELIABILITY AND VALIDITY OF UNILATERAL AND BILATERAL ISOMETRIC STRENGTH USING A CUSTOMISED, PORTABLE APPARATUS.

JOURNAL OF AUSTRALIAN STRENGTH AND CONDITIONING
(**PUBLISHED**, VOL 20, SUPPL. 1, PP. 61-67).

Nicolas H. Hart, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton

4.0. Abstract

Isometric strength assessments are often limited by the requirement to use large-scale, fixated equipment which can be expensive and difficult to relocate. Using a new, portable isometric apparatus, the purpose of this paper was to assess the reliability and validity of unilateral and bilateral isometric strength measures. Eleven recreationally trained men (age: 24.3 ± 2.2 yrs; mass: 81.1 ± 10.8 kg; height: 180.2 ± 2.8 cm) were required to perform a total of eighteen maximal isometric squat contractions, consisting of three bilateral [BL] and six unilateral (dominant [ULD] and non-dominant [ULN]) trials on each isometric device (fixated and portable). Trials were randomised and counterbalanced between each condition and apparatus. The portable device was able to validly and reliably measure peak force (CV < 4.7%; ICC > 0.961) and mean force (CV < 9.3%; ICC > 0.831) across all bilateral and unilateral conditions. However, the portable device was not able to reliably assess peak rate of force development (using a 30ms window), with a slightly elevated prevalence of typical error using BL (CV < 15.2; ICC > 0.943) and ULD (CV < 14.7; ICC > 0.931) conditions; and was substantially unreliable for ULN (CV < 45.5; ICC > 0.360) trials. The portable isometric device can therefore be used to successfully measure maximal lower body isometric strength using peak force and mean force outputs as descriptive measures.

4.1. Introduction

The ability to produce high levels of muscular force and power are considered to be essential determinants in successful athletic performance across a broad range of sports (Bevan et al, 2010; Haff et al, 2005; Harris, Cronin & Keogh, 2007; Nimphius, McGuigan & Newton, 2010). While conjecture continues to exist regarding the precise levels of strength required to optimise performance (McGuigan, Newton, Winchester & Nelson, 2010; Stone, Moir, Glastier & Sanders, 2002), the overriding conclusion drawn from a multitude of research upholds the positive relationship between maximal strength and athletic performance in sports reliant on strength, speed and power (Cronin & Hansen, 2005; Haff et al, 2005; McGuigan et al, 2010; Nimphius et al, 2010; Stone et al, 2002; Stone et al, 2003; Stone et al, 2005). In order to assess maximal strength, a variety of measures are available for use, including isotonic, isokinetic and isometric testing modalities (Izquierdo, Hakkinen, Gonzalez-Badillo, Ibanez & Gorostiaga, 2002; Morrissey, Harman & Johnson, 1995; Moss & Wright, 1993); however, a lack of consensus remains concerning the most suitable mechanism to assess muscle function due to inherent limitations and varying situational contexts (Cronin & Hansen, 2005 Harris et al, 2007; Morrissey et al, 1995; Moss & Wright, 1993; Nuzzo, McBride, Cormie & McCaulley, 2008).

Despite muscular expressions of strength and power remaining contextually specific (Baker, Wilson & Carlyon, 1994; Cronin, McNair & Marshall, 2002; Harris et al, 2007; Morrissey et al, 1995), measures of isometric strength have been shown to correlate well with dynamic strength when assessed within the same exercise domain (Haff et al, 2005; Stone et al, 2002; Wilson & Murphy, 1996). This isometric-dynamic relationship is primarily achievable by honouring the premise of positional specificity (Gamble, 2006; Wilson & Murphy, 1996; Wilson, Murphy & Walshe, 1996), which promotes the deliberate selection of exact joint angles and body positions in isometric protocols (Haff et al, 1997; Morrissey et al, 1995; Reilly, Morris & Whyte, 2009) that best correspond with the position of highest force production within the equivalent dynamic activity (Haff et al, 1997; Nuzzo et al, 2008). As isometric strength testing has other notable advantages, including high test-retest reliability (McBride, Cormie & Deane, 2006; McGuigan et al, 2010; Viitasalo, Saukkonen & Komi, 1980); greater task control (Demura, Miyaguchi, Shin & Uchida, 2010; Manabe, Yokozawa & Ogata, 2003); lower performance variability (McBride et al, 2006; McGuigan et al, 2010; Viitasalo et al, 1980); lower injury risk, incidence and severity (Blazevich, Gill & Newton, 2002; Demura et al, 2010); and simple test administration and data analysis processes (Blazevich et al, 2002); this might explain the popularity of isometric strength measures frequently used in research, clinical and athletic contexts (Blazevich et al, 2002; Haff et al, 2005; McGuigan et al, 2010; O'Shea & O'Shea, 1989).

While isometric testing protocols have many advantageous characteristics, there are limitations that require acknowledgement. In particular, the relationship of isometric strength to athletic performance is not as strong as those exhibited by dynamic strength testing mechanisms (Blazevich et al, 2002; Cardinale, Newton & Nosaka, 2011; Enoka, 2008). Furthermore, isometric protocols require a force-measuring device in order to acquire meaningful strength data (Demura et al, 2010; McGuigan et al, 2010). In spite of these limitations, muscle function tests using isometric protocols can provide necessary information regarding an athlete's capacity to produce maximal voluntary forces (Blazevich et al, 2002; Cardinale et al, 2011). This data can subsequently be used by coaches to produce a complete and proper assessment of an athlete's training status and so too the effectiveness of their training programs (Cardinale et al, 2011; Enoka, 2008). In support of this, previous research has successfully demonstrated the importance of maximal isometric strength in a variety of athletically and recreationally trained populations (Brughelli, Cronin, Levin & Chaouachi, 2008; Haff et al, 2005; McGuigan et al, 2010; O'Shea & O'Shea, 1989; Wilson & Murphy, 1996], using peak force [PF] and rate of force development [RFD] as descriptive measures of performance.

Historically, these assessment outcomes have been determined using expensive, large-scale, fixated devices which are notably limited by a lack of transportability, customisability, and affordability; demonstrating an inherent lack of practicality to real training and testing scenarios (Demura et al, 2010). In response to these constraints, a portable and fully customisable isometric assessment device has been developed which is relatively inexpensive; highly transportable; easy to set-up and administer; and is able to be used in any location at any given time. Although the portable apparatus has many practical benefits, the decreased stability of the device presents as a potential limitation as there are no bar supports to prevent horizontal sway which might influence the athlete's ability to produce a true reflection of their maximal force capabilities (McBride et al, 2006). It is therefore the purpose of this paper to assess the validity and reliability of the newly developed portable and customisable isometric assessment device in order to determine whether it is able to facilitate and derive valid representations of maximal strength and rate of force development characteristics, and whether it is able to do so in a reproducible manner.

4.2. Methods

4.2.1. Experimental Approach

Maximal bilateral and unilateral lower body isometric strength measures were performed using the isometric squat at preset hip and knee angles of 140° using both fixated and portable isometric assessment devices, to allow for maximal force production at zero velocity (Haff et al, 2005; Haff et al, 1997; Nuzzo et al, 2008; Paulus, Reiser & Troxell, 2004). Specific measures (peak force [PF], mean force [MF], rate of force development [RFD] and time to peak force [TTPF]) were identified using a portable force plate (400 series Performance Plate; Fitness Technology, Adelaide, Australia) sampling at 600Hz, and data acquisition software (Ballistic Measurement System [BMS]; Fitness Technology, Adelaide, Australia).

4.2.2. Participants

Eleven recreationally trained men (age: 24.3 ± 2.2 years; mass: 81.1 ± 10.8 kg; height: 180.2 ± 2.8 cm) were recruited for participation in this study. For participation eligibility into this study, subjects were required to have a minimum of twelve months resistance training experience, and participate in a recreational football competition. All subjects were absent of injury, and contraindication at the time of testing, and did not perform any lower body resistance training or vigorous physical activity within 48 hours prior to their testing session. The study was approved by the human ethics committee of Edith Cowan University. All athletes were notified of any potential risks involved, and provided written informed consent prior to commencement.

4.2.3. Equipment

A uniaxial, portable force plate (dimensions: 795 x 795 mm; maximum load: 1000 kg (9810 N)); standard 20kg Olympic barbell (mass: 20 kg; Australian Barbell Company, Victoria, Australia); and BMS data acquisition software were required for use across both isometric devices. The fixated isometric squat trials were performed using a floor-bolted power rack (Power Cage, Cybex International, MN, USA), with height adjustable bar supports, as presented in Figure 1. The portable isometric squat trials were performed using only a load-bearing, fully customisable heavy duty strap (SureTie, Zenith, NSW, Australia) designed to resist high loads (max: 4218 N (430 kg)), with an anti-retractible locking mechanism to prevent undue movement (loosening or tightening), and hooks to affix the strap to the barbell as presented in Figure 2. The primary difference of equipment between the portable and fixated apparatus involves the exchange of the large-scaled immovable rack, with the more affordable and transportable heavy duty load-bearing strap.

Figure 1. Frontal and side view of set-up and operation for the fixated isometric apparatus.

Figure 2. Frontal and side view of set-up and operation for the portable isometric apparatus.

4.2.4. Procedures

Subjects were required to perform a total of eighteen lower body maximal isometric squat contractions, consisting of three bilateral [BL]; and six unilateral (dominant [ULD] and non-dominant [ULN]) trials on each isometric assessment device (fixated and portable). The order of testing between both devices for all subjects was counterbalanced, with bilateral and unilateral trial-types fully randomised to negate the effects of muscular potentiation or fatigue (Hodgson, Docherty & Robbins, 2005; Rassier & MacIntosh, 2000). Subjects were provided with two minutes of passive recovery between each maximal effort, with a ten minute period of passive recovery during the changeover of isometric devices. Subjects were required to complete a sub-maximal familiarisation session one hour prior to the official testing procedure in order to determine subject-specific bar height settings for each apparatus, and to acclimatise them with the testing conditions of each isometric device.

At the commencement of the official testing period, participants had their height (cm) and weight (kg) measured using a wall-mounted stadiometer and electronic weighing scale. A general dynamic warm-up was provided, prior to a specific warm-up which included additional familiarisation efforts on each isometric strength device. A five minute recovery period was subsequently enforced. Prior to testing commencement, subjects were required to stand on the force plate while holding the barbell and remaining stationary, in order to offset the total mass of the system to zero within the BMS software. During official trials, the starting position for each device required the subjects to place slight upward pressure on the bar so that it is pressing against the supports (fixated device); or is pulling the straps taught (portable device). This was to ensure that no change in joint-angle was evident during maximal contraction, thus controlling the maximal contraction to commence at zero velocity (with no slight countermovement or jolting actions permitted).

For each bilateral trial, subjects adopted a traditional back squat position under the pre-set height of the bar, eliciting a hip and knee angle of 140° flexion (Figure 4) using a manual handheld goniometer. For each unilateral trial, subjects were required to reposition the active leg under their centre of mass, while removing their inactive leg from the force plate by flexing it at the knee (Figure 4). Due to unilateral repositioning, hip and knee angles of the active leg must be re-assessed using the goniometer to ensure the current bar-height settings meet the 140° joint angle criteria. Once subjects were in position, they were provided with specific instruction (Young, Pryor & Wilson, 1995) to "push as hard and as fast as you can, until I stay stop" in order to produce a rapid and sustained maximal contraction for five seconds in duration (Cardinale et al, 2011), and were provided with time to balance themselves. Once balanced and set in position, subjects were required to state “ready” to the researcher, prompting a 3-second verbal countdown: “3, 2, 1, GO” as test recording commenced. The researcher, and two research assistants, provided verbal encouragement to promote maximal efforts; visually monitored athlete technique during each trial to ensure postural and mechanical compensatory adjustments did not occur; and ensured athlete safety was maintained. This is particularly important when using the portable device, as there are no bar supports preventing undesirable horizontal movement or potential loss of balance during unilateral trials.

Figure 3. Correct subject positioning for bilateral (left) and unilateral (right) testing conditions.

For each bilateral and unilateral condition, two trials needed to produce peak force outputs within 5% of each other to be considered legitimate representations of the subjects maximal force production. If, within the 3 trials provided this was not achieved, a 4^{th} and 5^{th} trial per condition was permitted, with two minutes recovery provided per trial. No subject required more than 3 trials during this study, as adequate familiarisation was provided. For analysis purposes, the best trial for each condition across both devices was chosen to compare each athlete's performance between both isometric apparatus, identified by the trial with the greatest peak force [PF] output. In addition, within the portable isometric device, the best two trials for each trial-type were chosen using the same selection criteria in order to assess its reliability in measuring all dependent variables.

The dependent variables that were chosen for analysis were supplied by the BMS data acquisition software. The program, using the collected force-time data, identifies peak force [PF] as the highest force value produced during the maximal isometric contraction, with mean force [MF] and time to peak force [TTPF] determined from the point of curve inflection (onset of maximal contraction) to the moment of peak force production. Peak rate of force development [RFD] was also determined as the highest rate of force development produced within a 30ms window (epoch) between the onset of contraction and the peak force value.

4.2.5. Statistical Analysis

Isometric strength outputs, identified as peak force [PF], mean force [MF], peak rate of force development [RFD] and time to peak force [TTPF] were exported for analysis to Microsoft Excel (Microsoft, Redmond, WA) and analysed using a statistical analysis package (SPSS, Version 17.0; Chicago, IL). The portable isometric device was validated by using a dependent (paired) t-test to examine whether significant differences were prevalent between the isometric strength outputs obtained from the fixated and portable isometric devices. Statistical significance was set at an alpha level of $p \leq 0.05$ (with a 95% confidence level).

Intra-tester reliability and within-subject reliability for the portable isometric device were assessed by calculating the coefficient of variation (CV) and intraclass correlation coefficient (ICC). The strength of relationship for ICC coefficients was classified in accordance with Hopkins (Hopkins, 2000; Hopkins, 2002; Stone et al, 2002): $r \geq 0.3$ is moderate; $r \geq 0.5$ is strong; $r \geq 0.7$ is very strong; $r \geq 0.9$ is nearly perfect; and $r \geq 1.0$ is perfect. Coefficients of variation below 10% were considered reliable in accordance with other studies analysing biomechanical, and strength based human movement data (Augustsson et al, 2006; Cormack, Newton, McGuigan & Doyle, 2008; Cronin, Hing & McNair, 2004; Hunter, Marshall & McNair, 2004).

4.3. Results

The portable isometric device was only able to reliably determine peak force (CV < 4.7%; ICC > 0.961) and mean force (CV < 9.3%; ICC > 0.831) outputs under all bilateral and unilateral conditions. The portable device was therefore unable to reliably assess the peak rate of force development. Bilateral and dominant-leg unilateral conditions nearly reached reliable limits (CV < 15.2; ICC > 0.931), while surprisingly large variability was evident within non-dominant limb, unilateral trials (CV < 45.5; ICC > 0.360). This is likely due to the recreational training status of subjects, coupled with the reduced stability of the portable device. The portable device might be suitable for athletes of sub-elite or elite status, though this requires further investigation.

Additionally, the portable isometric device was able to accurately determine all descriptive measures when compared with the previously validated fixated apparatus (Blazevich et al, 2002). No significant differences ($p \leq 0.05$) were found between all strength outputs (peak force, mean force and peak rate of force development), or between the time to reach peak force during the more stable, bilateral condition. The only statistical difference noted between the two devices were found when comparing the times taken to peak force under both unilateral isometric trials ($p < 0.001$), with athletes requiring an extra second to produce maximal strength when using the portable device.

Table 1. Descriptive statistics (Mean and Standard Deviation) for all variables assessed using the fixated and portable isometric devices.

	PF	MF	RFD	TTPF
FIXATED				
- **BL**	2623 (± 653)	1880 (± 471)	8275 (± 4284)	2.91 (± 0.62)
- **UL (ND)**	1952 (± 482)	1442 (± 429)	5130 (± 2187)	2.96 (± 0.55)
- **UL (D)**	1958 (± 411)	1447 (± 403)	6268 (± 3234)	3.01 (± 0.53)
PORTABLE				
- **BL**	2583 (± 557)	1797 (± 463)	7521 (± 3856)	3.06 (± 0.56) [a]
- **UL (ND)**	1989 (± 476)	1496 (± 315)	4474 (± 1925)	4.01 (± 0.48) [a]
- **UL (D)**	1974 (± 392)	1466 (± 349)	5923 (± 2872)	3.94 (± 0.54) [a]

Note: Values are expressed as mean ± *SD*.
[a] Statistically significant difference ($p \leq 0.05$) found between portable and fixated devices.

Table 2. Between trial variance, and intra-tester reliability for peak force [PF], mean force [MF], and rate of force development [RFD] between each trial type using the portable isometric device.

	Bilateral Squat			Unilateral Squat [ND]			Unilateral Squat [D]		
	PF [a,b]	MF [a,b]	RFD [b]	PF [a,b]	MF [a,b]	RFD	PF [a,b]	MF [a,b]	RFD [b]
CV	3.6	8.4	15.2	3.6	9.3	45.5	4.7	6.1	14.5
ICC	0.973	0.906	0.943	0.980	0.831	0.360	0.961	0.950	0.931

Note: ND = Non-dominant limb, D = Dominant limb.
[a] Variables within CV criteria (CV < 10%).
[b] Variables with very strong ICC criteria (ICC > 0.7).

Table 3. Statistical differences and effect-size calculations between fixated and portable isometric devices for peak force [PF], mean force [MF], rate of force development [RFD], and time to peak force [TTPF].

	Bilateral Squat				Unilateral Squat [ND]				Unilateral Squat [D]			
	PF	**MF**	**RFD**	**TTPF**	**PF**	**MF**	**RFD**	**TTPF**	**PF**	**MF**	**RFD**	**TTPF**
P	0.311	0.408	0.352	0.436	0.323	0.377	0.110	0.001[a]	0.635	0.755	0.538	0.001[a]
ES	0.07	0.18	0.18	0.25	0.08	0.14	0.32	2.03[c]	0.04	0.05	0.11	1.74[b]

Note: ND = Non-dominant limb, D = Dominant limb, ES = Effect Size.
[a] Statistically significant difference ($p \leq 0.05$) found between portable and fixated devices.
[b] Large effect size (≥ 1.2 to < 2.0) evident between devices (Hopkins, 2000; Hopkins, 2002).
[c] Very Large effect size (≥ 2.0 to < 4.0) evident between devices (Hopkins, 2000; Hopkins, 2002).

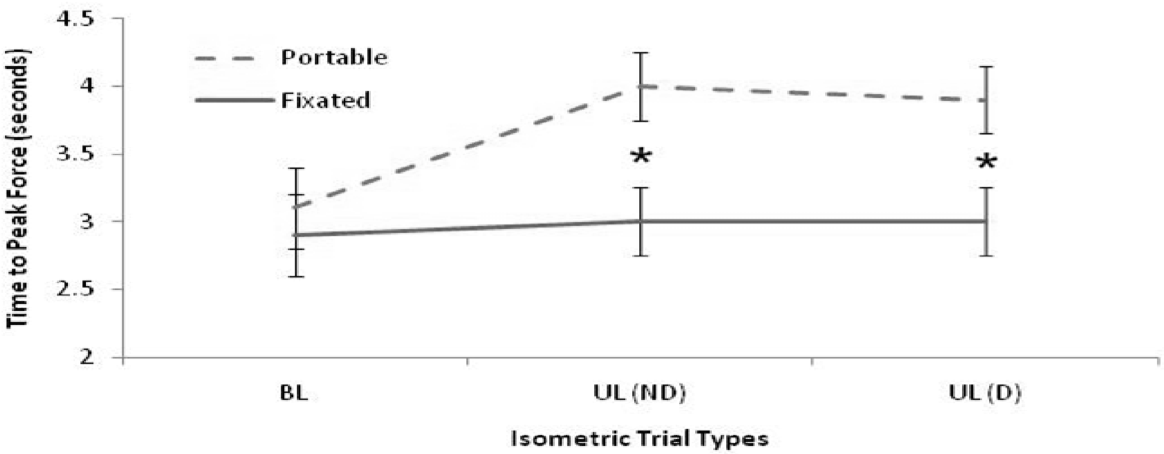


Figure 4. Time taken (in seconds) to produce peak force [PF] for each isometric apparatus, when performing bilateral, and unilateral (non-dominant [ND] and dominant [D] leg) maximal isometric contractions.

4.4. Discussion

Maximum isometric strength is an important physical characteristic, contributing to successful performance in a variety of sporting contexts (Bevan et al, 2010; Brughelli et al, 2008; Haff et al, 2005; Nimphius et al, 2010; Stone et al, 2005]. Previous research has demonstrated the importance of maximal isometric strength (peak force [PF]) and the development of power (rate of force development (RFD)) in a variety of athletic (Brughelli et al, 2008; Cronin & Hansen, 2005; Haff et al, 2005; Nuzzo et al, 2008) and recreationally trained (McGuigan et al, 2010) populations, with these studies demonstrating high correlations between isometric strength tests and 1-repetition maximum (1RM) tests (Blazevich et al, 2002; Viitasalo et al, 1980; Wilson et al, 1996). However, these outcomes have been assessed using expensive, large-scale, fixated devices. As there is a need for portable testing devices, it was the purpose of this study was to assess the validity and reliability of force measurements produced when using a new, portable and customisable isometric strength device. This was examined through using the isometric back squat exercise to illicit maximal isometric strength under bilateral and unilateral performance conditions across both portable and fixated isometric apparatus.

The results of this study successfully validate the new portable device when comparing obtained performance variables against a previously validated isometric device (Blazevich et al, 2002; McGuigan et al, 2010). In particular, all descriptive measures (peak force, mean force and rate of force development) were statistically even, with no significant differences ($p \leq 0.05$) between the two devices, producing P-values above 0.737, 0.681 and 0.366 respectively. Interestingly, time taken to reach peak force under unilateral conditions were significantly different between the two devices with athletes requiring an extra second of time to achieve peak force production (3 seconds using fixated; 4 seconds using portable). This was expected as the portable device requires additional balance, with the initial period of time used by the athlete to stabilise under the bar prior to producing maximal leg drive. In this regard, athletes using the portable device should be given an extra second of time to derive their peak force outputs under maximal testing conditions.

Furthermore, the portable isometric device has upheld the high reliability of maximal isometric strength protocols (McGuigan et al, 2010; Viitasalo et al, 1980), producing very strong correlations (ICC > 0.831) for all descriptive measures. The rate of force development for the non-dominant limb, during unilateral trials, was the main exception, with a moderate correlation (ICC > 0.360) that was additionally confirmed by the high coefficient of variation (CV < 45.5) in this trial type. The typical error prevalent within the data, which represents a useful measure of reliability within athletic performance (Blazevich et al, 2002; Hopkins, 2000), was also determined, demonstrating high reliability for peak force and mean force outputs across both isometric devices (CV < 9.3). The rate of force development during bilateral and dominant-leg unilateral conditions was only able to approach acceptable limits (CV < 15.2), however this may have been confounded by the training status of the recreationally trained men used within this study, who routinely produce greater performance variability within human movement (Salonikidis et al, 2009). Similar volatility in rate of force development outputs have also been noted in previous research featuring maximal isometric strength assessments (McGuigan et al, 2008; McGuigan et al, 2010; McGuigan & Winchester, 2008), highlighting the need for a cautious approach when interpreting rate of force development measurements under this isometric testing scenario, with further research efforts necessary.

The portable isometric apparatus was shown to be an efficient, convenient, valid and reliable assessment tool for maximal isometric strength, which is able to be used as an effective indicator of dynamic performance within this population. The findings of this study substantiate that this new, fully customisable and portable device can be used to accurately and reliably assess peak force, and mean force outputs under bilateral and unilateral testing conditions, with rate of force development measures to be interpreted with caution. Users of this device should provide their athletes with an extra second of maximal effort during unilateral strength trials to ensure the peak is achieved; and should allow substantial familiarisation to allow the athlete to adapt to the less stable nature of this new device. Future studies may wish to investigate the reliability of this apparatus when using the isometric mid-thigh pull or other potential isometric exercises. Further, the unstable nature of the portable testing apparatus may have application in measures of strength when balance is an important component of the target sport performance.

4.5. Practical Applications

This apparatus provides strength and conditioning professionals with a more affordable, pragmatic, portable and easy-to-administer method to test, monitor and train unilateral and bilateral lower body isometric strength at any customisable joint angle, at any time, and in any location. In particular, it presents as a suitable alternative to the fixated apparatus during times when the large-scaled equipment is unavailable or unattainable. Coaches may wish to invest in portable, height-adjustable bar supports (if convenient) to increase the stability of the device in the applied, real-world environment. Furthermore, coaches may also wish to use this device to further assess and develop strength under less stable conditions as a tool to promote this component within their particular sport.

4.6. References

Augustsson, J., Thomee, R., Linden, C., Folkesson, M., Tranberg, R., & Karlsson, J. (2006). Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. *Scandinavian Journal of Medicine and Science in Sports, 16*(2), 111-120.

Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology and Occupational Physiology, 68*(4), 350-355.

Bevan, H. R., Bunce, P. J., Owen, N. J., Bennett, M. A., Cook, C. J., Cunningham, D. J., et al. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research, 24*(1), 43-47.

Blazevich, A. J., Gill, N., & Newton, R. U. (2002). Reliability and validity of two isometric squat tests. *Journal of Strength and Conditioning Research, 16*(2), 298-304.

Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine, 38*(12), 1045-1063.

Cardinale, M., Newton, R., & Nosaka, K. (2011). *Strength and Conditioning: Biological Principles and Practical Applications*: Wiley-Blackwell.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance, 3*(2), 131-144.

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength Conditioning Research, 19*(2), 349-357.

Cronin, J. B., Hing, R. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research, 18*(3), 590-593.

Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Is velocity-specific strength training important in improving functional performance? *Journal of Sports Medicine and Physical Fitness, 42*(3), 267-273.

Demura, S., Miyaguchi, K., Shin, S., & Uchida, Y. (2010). Effectiveness of the 1RM estimation method based on isometric squat using a back-dynamometer. *Journal Strength & Conditioning Research, 24*(10), 2742-2748.

Enoka, R. (2008), *Neuromechanics of Human Movement* (4th ed.). Champaign, IL: Human Kinetics.

Gamble, P. (2006). Implications and Applications of Training Specificity for Coaches and Athletes. *Journal of Strength and Conditioning, 28*(3), 54-58.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., et al. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women Olympic weightlifters. *Journal of Strength and Conditioning Research, 19*(4), 741-748.

Haff, G. G., Stone, M. H., O'Bryant, H., Harman, E., Dinan, C., Johnson, R., et al. (1997). Force-time dependent characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research, 11*, 269-272.

Harris, N., Cronin, J., & Keogh, J. (2007). Contraction force specificity and its relationship to functional performance. *Journal of Sports Science, 25*(2), 201-212.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-Activation Potentiation: Underlying physiology and implications for motor performance. *Sports Medicine, 35*(7), 585-595.

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1-15.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Hunter, J. P., Marshall, R. N., & McNair, P. (2004). Reliability of biomechanical variables of sprint running. *Medicine and Science in Sports and Exercise*, *36*(5), 850-861.

Izquierdo, M., Hakkinen, K., Gonzalez-Badillo, J. J., Ibanez, J., & Gorostiaga, E. M. (2002). Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology, 87*(3), 264-271.

Manabe, Y., Yokozawa, T., & Ogata, M. (2003). Effect of load variation on lower muscle activity and joint torque during parallel squats. *Japanese Journal of Physical Fitness and Sports Medicine*, *52*, 89-98.

McBride, J., Cormie, P., & Deane, R. (2006). Isometric squat force output and muscle activity in stable and unstable conditions. *Journal of Strength and Conditioning Research, 20*(4), 915-918.

McGuigan, M. R., Newton, M. J., & Winchester, J. B. (2008). Use of isometric testing in soccer players. *Journal of Australian Strength and Conditioning, 16*, 11-14.

McGuigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. *Journal of Strength and Conditioning Research*, *24*(9), 2570-2573.

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science and Medicine, 7*, 101-105.

Morrissey, M. C., Harman, E. A., & Johnson, M. J. (1995). Resistance training modes: specificity and effectiveness. Medicine and Science in Sports and Exercise, 27(5), 648-660.

Moss, C. L., & Wright, P. T. (1993). Comparison of three methods of assessing muscle strength and imbalance ratios of the knee. *Journal of Athletic Training, 28*(1), 55-58.

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research, 24*(4), 885-895.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707.

O'Shea, K., & O'Shea, J. (1989). Functional Isometric Weight Training: Its effects on Dynamic and Static strength. *Journal of Applied Sport Science Research, 3*(2), 30-33.

Paulus, D. C., Reiser, R. F., 2nd, & Troxell, W. O. (2004). Pneumatic strength assessment device: design and isometric measurement. *Biomedical Sciences Instrumentation, 40*, 277-282.

Rassier, D., & MacIntosh, B. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*, 499-508.

Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: a review. *Journal of Sports Science, 27*(6), 575-589.

Salonikidis, K., Amiridis, I. G., Oxyzoglou, N., de Villareal, E. S., Zafeiridis, A., & Kellis, E. (2009). Force variability during isometric wrist flexion in highly skilled and sedentary individuals. *European Journal of Applied Physiology, 107*(6), 715-722.

Stone, M. H., Moir, G., Glaister, M., & Sanders, R. (2002). How much strength is neccessary? *Physical Therapy in Sport, 3,* 88-96.

Stone, M. H., O'Bryant, H. S., McCoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research, 17*(1), 140-147.

Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U. (2005). Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise, 37*(6), 1037-1043.

Viitasalo, J. T., Saukkonen, S., & Komi, P. V. (1980). Reproducibility of measurements of selected neuromuscular performance variables in man. *Electromyography and Clinical Neurophysiology, 20*(6), 487-501.

Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine, 22*(1), 19-37.

Wilson, G. J., Murphy, A. J., & Walshe, A. (1996). The specificity of strength training: the effect of posture. *European Journal of Applied Physiology and Occupational Physiology, 73*(3-4), 346-352.

Young, W., Pryor, J., & Wilson, G. (1995). Effect of Instructions on Characteristics of Countermovement and Drop Jump Performance. *Journal of Strength and Conditioning Research, 9*(4), 232.

CHAPTER FIVE – STUDY THREE

LEG MASS CHARACTERISTICS OF ACCURATE AND INACCURATE KICKERS: AN AUSTRALIAN FOOTBALL PERSPECTIVE.

JOURNAL OF SPORT SCIENCES
(IN REVIEW, JANUARY 2012).

Nicolas H. Hart, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton

5.0. Abstract

Understanding the influence physical characteristics may have on the generation of kicking accuracy is notably advantageous. The aim of this paper was to provide a detailed profile of the lower limb mass characteristics between accurate and inaccurate Australian footballers. Thirty-one players were recruited from the Western Australian Football League to perform the drop punt kicks over twenty metres to a player target. Players were separated into accurate (n = 15) and inaccurate (n = 16) groups, with leg mass characteristics assessed using whole body DEXA scans. Accurate kickers contained significantly greater relative lean mass (p = 0.001 to 0.004) and significantly lower relative fat mass (p = 0.001 to 0.024) across all segments of the kicking and support limbs, while also exhibited significantly higher lean-to-fat mass ratios within all segments across both limbs (p = 0.001 to 0.009). Inaccurate kickers displayed significantly larger asymmetries between their kicking and support limbs than accurate kickers (p = 0.005 to 0.028), showing notably lower lean mass in their support limb. These results illustrate considerably different lower limb characteristics between accurate and inaccurate kickers in Australian football, demonstrating the possible influence segmental mass characteristics may have on the technical proficiency of the drop punt.

5.1. Introduction

Australian football is a fast-paced, dynamic and multidimensional field-based sport requiring a unique combination of physical, technical, mental and tactical attributes to successfully compete at the professional level (Young & Pryor, 2007; Young et al, 2005). The recruitment process of the Australian Football League (AFL) strives to assess these attributes through a variety of standardised anthropometric, physical fitness and technical skill-based assessments (Pyne, Gardner, Sheehan & Hopkins, 2006) which are benchmarked against historical data and reference values to assist with the decision making process (Keogh, 1999; Nevill, Holder & Watts, 2009; Pyne, Gardner, Sheehan & Hopkins, 2005). Athletic profiling, in this manner, provides a valuable mechanism to identify talent, player strengths and weaknesses, position suitability, and to assist in the optimal design of strength and conditioning programmes (Veale, Pearce, Buttifant & Carlson, 2010; Chaouachi et al, 2009; Pyne et al, 2006).

Alternatively, football sports have also profiled their athletes comparatively to other populations (Nevill et al, 2009), particularly spanning their developmental pathways, including senior-to-junior (Veale et al, 2010; Hoshikawa et al, 2009), elite-to-sub elite (Veale et al, 2010; Keogh, 1999) and starter-to-non starter comparisons (Young et al, 2005). The observations drawn from such investigations are able to provide valuable descriptive information concerning the potential discrepancies inherent within players aspiring to reach professional status; or to serve as a benchmark for monitoring athletes currently within elite ranks. While previous research provides insight into descriptive data within various levels of playing performance (Veale et al, 2010; Young & Pryor, 2007), there is an absence of research investigating the applicability of this data to technical proficiency and performance. In particular, no studies to date have attempted to describe the physical characteristics of accurate and inaccurate kickers in any football code.

The optimisation of kicking performance is an integral focus within Australian football, as the outcome of a competitive match can often be decided on the basis of a single kick (Young et al, 2010; Dichiera et al, 2006). In particular, athletes who are able to deliver a ball more accurately over longer distances to an intended target or location provide a distinct tactical advantage to their team (Young & Rath, 2011; Ball, 2008). While limited research has been produced to explore the biomechanical and physiological descriptors of kicking accuracy outcomes (Young et al, 2010; Dichiera et al, 2006), an absence of attention has been provided to investigate the link between those parameters modifiable by athletic conditioning and their subsequent influence on kicking performance. In particular, the quantity (amount) and quality (composition) of lower limb mass may have a profound impact on the technical and temporal strategy of an athlete's kicking action (Young & Rath, 2011).

Given that successful athletes are characteristically different than less successful athletes (Nevill et al, 2009; Rampini, Impellizzeri, Castagna, Coutts & Wisloff, 2009); and kicking accuracy is highly important in Australian Football, it seems appropriate to examine the interrelationships between the physical characteristics of accurate and inaccurate kickers in relation to their level of technical proficiency. In particular, it is of interest to identify the potential relationships between leg mass characteristics of accurate and inaccurate kickers as a tool to better understand the influence it may have on the generation and regulation of kicking accuracy outcomes. The purpose of this paper is to assess and compare the segmental characteristics of the lower limbs (kicking leg and support leg) between accurate and inaccurate Australian footballers as a mechanism to identify whether any segmental characteristics are associated with more consistent and successful kicking performances.

5.2. Methods

5.2.1. Participants

Thirty-one Australian footballers (age: 22.1 ± 2.8 yrs; mass: 85.1 ± 13.0 kg; height: 181.1 ± 7.0 cm; BMI: 25.9 ± 3.2) were recruited from the Western Australian Football League (WAFL) for participation within this study. All athletes had a minimum of five years total playing experience, with at least two consecutive years of experience at their current playing level. Athletes were void of injuries and contraindications at the time of testing; and were not permitted to perform any strenuous exercise or lower body resistance training within 48 hours of their assigned testing session. All athletes were notified of the potential risks involved, and provided written informed consent for participation. Ethics clearance was provided by Edith Cowan University's Human Ethics Committee.

5.2.2. Study Design

This study utilised an acute, between groups, cross-sectional design consisting of a single two hour testing session. Testing sessions commenced with anthropometric measures including height, weight and limb length; followed by an assessment of whole-body composition and lower body segmental mass characteristics (lean, fat, total) of the thigh, shank and foot across both kicking and support limbs using dual energy x-ray absorptiometry (DEXA). Athletes were then taken through a general dynamic warm-up, followed by a mechanically specific warm-up (kicking over variable distances), in order to stabilise their kicking performance (Amiri-Khorasani, Osman & Yusof, 2010). The kicking protocol (drop punt over 20 metres) was then completed. Subjects were required to wear their club issued football shorts; and were provided with indoor football shoes (Nike5 Bomba, Nike Inc, USA) for use during the testing session. All athletes were thoroughly familiarised with all testing procedures prior to the commencement of testing. Following the assessment and analysis of their kicking performance, subjects were subsequently assigned to accurate (n = 15) and inaccurate (n = 16) groups for further analysis (Table 1), in accordance with specific accuracy determination criteria.

Table 1. Subject characteristics for accurate and inaccurate groups.

Subject Characteristics	Accurate Kickers	Inaccurate Kickers
Age (yrs)	21.7 (± 3.3)	23.1 (± 1.9)
Height (cm)	181.7 (± 6.7)	180.8 (± 7.3)
Weight (kg)	80.6 (± 8.0)	89.4 (± 15.2) [a]
Body Mass Index (BMI)	24.4 (± 1.5)	27.3 (± 3.8) [a]
Total Body Fat (%)	11.1 (± 2.0)	17.4 (± 5.2) [a]
Kicking Leg Length (cm)	87.3 (± 3.3)	85.7 (± 3.6)
Lean Mass Imbalance [b]	1.00 (± 0.0)	1.03 (± 0.0) [a]
Kicking Accuracy (%)	91.3 (± 11.3)	57.5 (± 16.4) [a]

Note: Values are expressed as mean ± *SD*.
[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.
[b] Lean Mass Imbalance calculated as total kicking leg lean mass divided by total support leg lean mass.

5.2.3. Anthropometrics

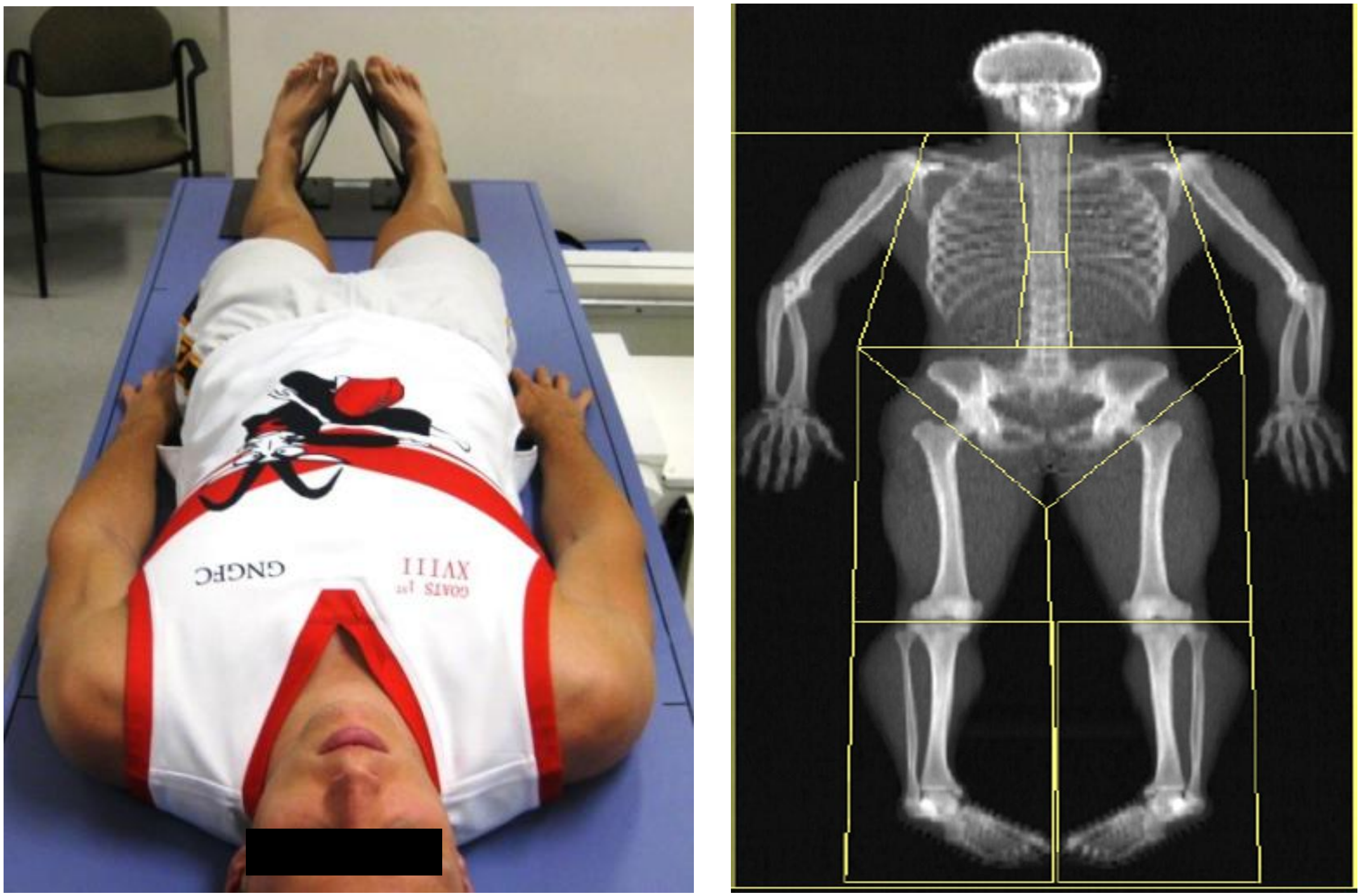
Standing height was recorded to the nearest 0.1 centimetre using a wall-mounted stadiometer, with body weight recorded to the nearest 0.1 kilogram using a standard electronic weighing scale. Limb length of the kicking leg was assessed using an anti-retractible measuring tape, from the greater trochanter of the Femur (proximal end), to the lateral malleolus of the Fibula (distal end), and was recorded to the nearest 0.1 centimetre. Standing height and limb length measures were performed three times for each subject, with the average of the three trials retained for analysis.

5.2.4. Scan Procedure

Lower body segmental mass and full-body composition components were assessed with dual energy x-ray absorptiometry (DEXA; Hologic Discovery A, Waltham, WA) using previously established, standardised and reliable body positioning procedures (Hologic, 2004; Peiffer et al, 2010). In particular, subjects assumed a stationary, supine position on the scanning bed with both arms pronated by their side, and hands facing the table. To ensure consistent body positioning, the DEXA operator manually assisted subjects in order to straighten their head, torso and pelvis; internally rotate and fixate their legs and feet at 45°; and ensured they were located within the DEXA scanning zone (Figure 1a). This has been shown to produce a scan/re-scan coefficient of variation below 1% in our laboratory (Peiffer et al, 2010).

5.2.5. Scan Analysis

Whole body scans were analysed using the inbuilt analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, WA). The predefined, mandatory whole body model (Hologic, 2004) was applied to the scan image, separating the body into axial and appendicular sections to determine whole body composition and segmental composition of the kicking and support legs. Further analysis was performed to specifically identify and assess the segmental mass characteristics of the thigh and shank regions of the kicking and support legs using the sub-region analysis tool, in accordance with Dempster's body segment parameter boundaries for 2D studies (Winter, 1990). Scan analysis reliability assessed prior to the current study revealed very high intra-tester reliability (CV $\leq$ 2.6%; ICC $\geq$ 0.941) and very high inter-tester reliability (CV $\leq$ 2.4%; ICC $\geq$ 0.961) for segmental sub-region analysis components.



(A) **(B)**

Figure 1. The DEXA scan and analysis process, with (A) a frontal view of the subject positioning process, illustrating pronated arms, and internally rotated thighs using a positioning device; and (B) the whole body, and segmental analysis zones used to define the lower body

Due to the lengthening of the shank segment during the kicking motion in response to fixed plantarflexion of the foot (Orchard, Walt, McIntosh & Garlick, 1999), the shank segment was represented by the combination of both shank and foot regions in this study (Figure 1b). Segmental mass outputs were categorised into fat mass (g), lean mass (g) and total mass (g) values for each sub-region across all scans and subjects using Microsoft Excel (Microsoft, Redmond, WA). Relative lean mass for each segment and limb was calculated by dividing the amount segmental mass (g) by total body mass (g). The lean-to-fat ratio for each segment and limb was calculated by dividing the quantity of lean mass (g) over the quantity of fat mass (g) within the specific limb or segment. The residual difference between the kicking and support legs for each mass component (lean, fat and total) was determined by deducting the whole support leg from the whole kicking leg using both absolute and relative computations.

5.2.6. Kicking Protocol

Kicking technique was assessed using the drop punt kick, performed with an Australian football (450g, Sherrin, Victoria, AU) inflated to official air pressure specifications (67 – 75 kPa) (Ball, 2008), using an electronic air pump (Air Erupt, Volcano, Taiwan). Athletes were required to produce ten drop punt kicks to a stationary human (player) target situated 20 metres from the centre of the kicking zone with the intention to deliver the ball as accurately as possible to the specified target (Figure 2). The twenty meter distance was chosen to correspond with other kicking accuracy literature in Australian Football (Young et al, 2010; Dichiera et al, 2006), and to replicate game-based accuracy demands when kicking to another player, as short kicks are often used to deliver a ball to another player in

Australian Football (Dichiera et al, 2006). A life-sized obstacle representing an opposite player (base-to-head height: 6 ft; base-to-hand height: 7 ft) was positioned between the kicker and their target to control for minimum kicking trajectory, and to increase game-test specificity in the laboratory environment as Australian Footballers are regularly required to kick a ball to another player over an opponent defending space on the field.

Prior to commencing the kicking protocol, subjects completed a series of mechanically specific warm-up sets (5 drop punt kicks over 20m, 30m and 40m respectively, totalling 15 warm-up trials). Their ten official drop punt trials were then completed with a one minute recovery provided between each kick. For the trial to be considered successful, the athlete had to produce an approach consisting of at least two steps prior to planting their foot within the assigned kicking zone. Any trials which did not meet this criterion were considered invalid, and a repeat kicking trial subsequently provided until ten successful kicks were produced. Angle of approach was not standardised, however all athletes voluntarily self-selected a straight approach.

5.2.7. Accuracy Determination

Kicking accuracy was assessed using a customised numerical scoring system. All kicks were visually graded immediately following each trial by the lead researcher; the human target (receiving the ball) and a research assistant. All assigned scores were recorded and visually confirmed using a two-dimensional digital video camera (MV710I PAL, Canon, NSW, AU). The scoring system for each kick spanned from 1 (accurate), 2 (moderate) and 3 (inaccurate), and was judged by the location of ball delivery to the target (Table 2).

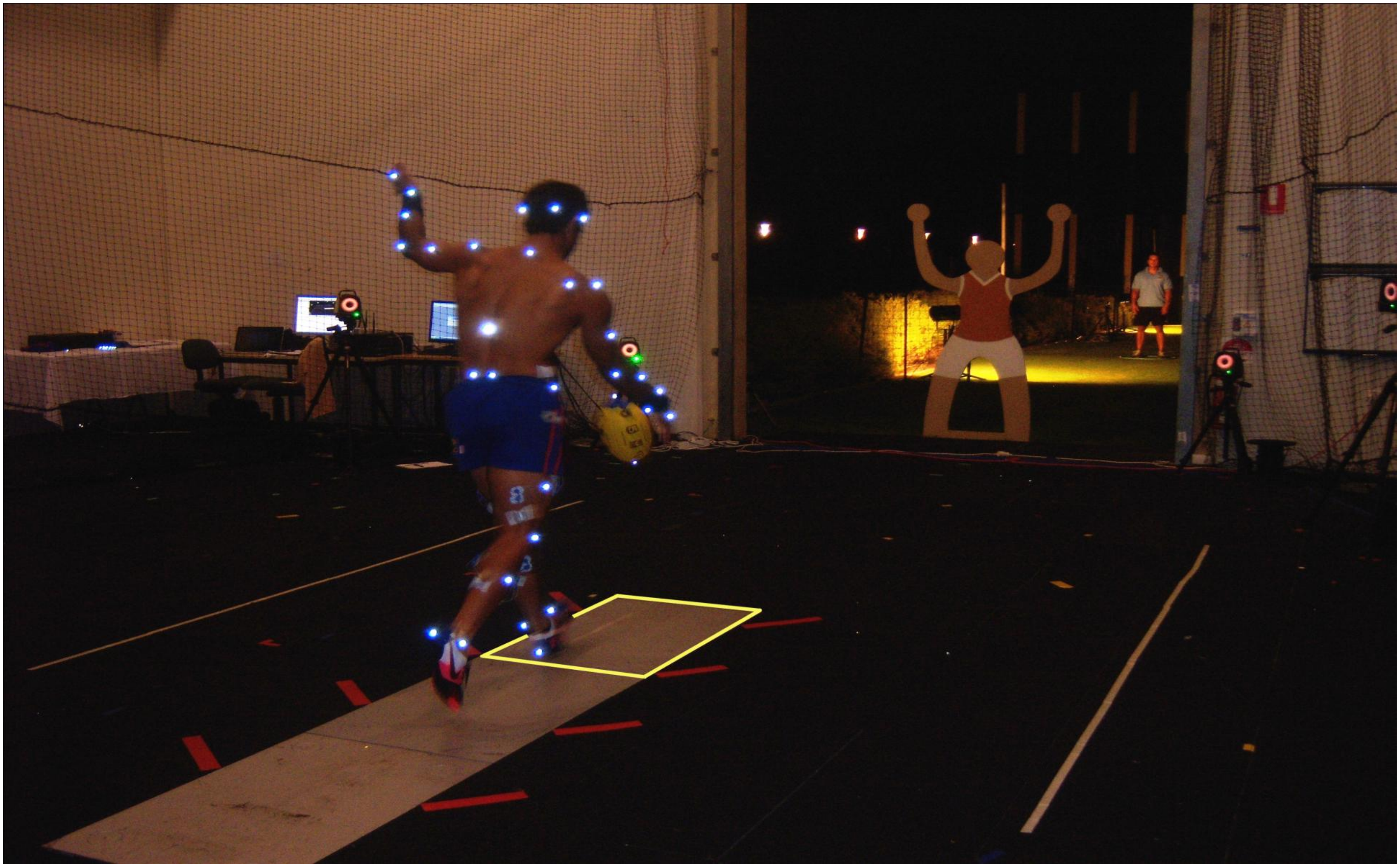


Figure 2. The kicking protocol set-up, with the athlete performing the drop punt, over an obstacle (height: 6 ft), to a stationary human target 20 metres from the kicking zone (outlined, dimensions: 1.0m x 0.7m).

Following ten successful kicks, each athlete's scores were summated, with total scores ranging between 10 to 30 points. Athletes were classified as either accurate (10 – 18 points) or inaccurate (19 – 30 points), resulting in fifteen accurate kickers, and sixteen inaccurate kickers. Kicking accuracy was subsequently determined by calculating the percentage of accurate trials produced within the ten trial quota. Athlete performance and accuracy grading reliability assessed prior to the current study revealed very high intra-tester reliability (CV ≤ 1.6%; ICC ≥ 0.997), inter-tester reliability (CV ≤ 3.3%; ICC ≥ 0.986) and between-day reliability of kicking performance (CV ≤ 4.2%; ICC ≥ 0.975).

Table 2. Accuracy grading and determination criteria for human target kicking outcomes.

Assigned Score	Description of Ball Delivery to Target
1 (Accurate)	The ball is delivered directly to the target, between the waist and head of the receiving player. The target should not reach or jump in any direction from their stationary position for this score to be awarded.
2 (Moderate)	The ball slightly deviates from the target, though not excessively (within the targets reach). The target may take one step or reach in any direction; jump directly upwards; or kneel down from their stationary position for this score to be awarded. No combined "step and reach" or "jump and reach" are allowed.
3 (Inaccurate)	The ball misses the target by any margin beyond the limits seen within the 'Accurate' or 'Moderate' grading criteria. If the target needs to step and reach; jump and reach; or take more than one step to receive the ball, or, if the ball misses the target zone all together; it is awarded an inaccurate score.

5.2.8. Statistical Analysis

Independent t-tests were used to determine whether significant differences were prevalent between subject characteristics (Table 1) and leg mass characteristics (Table 3) of accurate and inaccurate kicking groups. Statistical significance was set at an alpha level of $p \leq 0.05$. Furthermore, Pearson's product moment (PPM) correlation coefficients (r) were calculated to determine the strength of relationship between absolute and relative leg mass variables to total kicking accuracy scores (Table 4), as per accuracy determination criteria. The strength of relationship was classified in accordance with Hopkins (2002): $r \geq 0.3$ is moderate; $r \geq 0.5$ is strong; $r \geq 0.7$ is very strong; $r \geq 0.9$ is nearly perfect; and $r = 1.0$ is perfect. The data was assessed for normality and scale of measurement. All statistical computations were performed using a statistical analysis program (SPSS, Version 17.0; Chicago, IL).

5.3. Results

Leg mass characteristics have been provided in Table 3. Significant differences between accurate and inaccurate kickers for absolute mass and relative mass (proportionate to total body mass) quantities of the thigh, shank and whole leg segments were evident within the kicking leg (Figure 3) and support leg (Figure 4). In particular, no significant differences were noted for absolute lean mass and absolute total mass across all kicking leg and support leg segments, with only absolute fat mass reaching significance in both kicking ($p = 0.001$ to 0.013) and support ($p \leq 0.001$) legs, demonstrating lower fat mass in accurate kickers across all segments. When expressed in relative terms (proportionate to total body mass), a greater interaction between composite mass and kicking accuracy was observed across both limbs. In particular, lean mass was significantly higher ($p = 0.001$ to 0.004), and fat mass was significantly lower ($p = 0.001$ to 0.024) in accurate kickers across all segments in both kicking and support limbs. No difference was found in total relative thigh mass for either limb, however accurate kickers did exhibit significantly higher total relative shank mass ($p = 0.002$ to $p = 0.013$) across both limbs, and higher total relative leg mass ($p = 0.048$) in the support leg only.

Table 3. Leg mass characteristics of kicking and support limbs for accurate and inaccurate kickers.

LEG MASS CHARACTERISTICS	Accurate [Kicking Leg]	Inaccurate [Kicking Leg]	Accurate [Support Leg]	Inaccurate [Support Leg]
Absolute Mass of Thigh				
- Lean (g)	8173.8 (± 885.7)	8246.4 (± 1356.9)	8115.6 (± 922.6)	7967.4 (± 1378.4)
- Fat (g)	1190.2 (± 355.1)	2199.6 (± 898.0) [a]	1175.9 (± 363.0)	2138.8 (± 838.6) [a]
- Total (g)	9625.6 (± 1064.9)	10745.8 (± 1985.7)	9601.0 (± 1170.5)	10401.60 (± 1942.6)
Absolute Mass of Shank				
- Lean (g)	3739.3 (± 364.9)	3559.5 (± 455.0)	3783.3 (± 362.2)	3507.6 (± 454.1)
- Fat (g)	574.2 (± 168.4)	809.7 (± 300.4) [a]	473.8 (± 121.3)	855.9 (± 326.8) [a]
- Total (g)	4655.5 (± 471.9)	4715.0 (± 655.4)	4596.5 (± 409.3)	4706.8 (± 643.8)
Absolute Mass of Leg				
- Lean (g)	11913.1 (± 1170.2)	11805.9 (± 1720.1)	11898.9 (± 1183.5)	11474.9 (± 1716.5)
- Fat (g)	1764.4 (± 483.3)	3016.7 (± 1179.5) [a]	1649.7 (± 462.7)	2994.7 (± 1147.0) [a]
- Total (g)	14281.2 (± 1495.8)	15460.8 (± 2566.8)	14197.5 (± 1511.9)	15108.4 (± 2503.9)

Relative Mass of Thigh				
- Lean (%)	10.14 (± 0.6)	9.36 (± 0.8) [a]	10.06 (± 0.5)	9.03 (± 0.8) [a]
- Fat (%)	1.46 (± 0.4)	2.44 (± 0.8) [a]	1.44 (± 0.4)	2.37 (± 0.7) [a]
- Total (%)	11.93 (± 0.4)	12.14 (± 0.7)	11.89 (± 0.5)	11.75 (± 0.7)
Relative Mass of Shank				
- Lean (%)	4.65 (± 0.3)	4.08 (± 0.5) [a]	4.70 (± 0.3)	4.01 (± 0.5) [a]
- Fat (%)	0.71 (± 0.2)	0.90 (± 0.2) [a]	0.58 (± 0.1)	0.96 (± 0.3) [a]
- Total (%)	5.78 (± 0.3)	5.37 (± 0.4) [a]	5.71 (± 0.2)	5.37 (± 0.4) [a]
Relative Mass of Leg				
- Lean (%)	14.79 (± 0.7)	13.44 (± 1.1) [a]	14.77 (± 0.6)	13.05 (± 1.1) [a]
- Fat (%)	2.16 (± 0.5)	3.35 (± 1.0) [a]	2.03 (± 0.5)	3.33 (± 1.0) [a]
- Total (%)	17.71 (± 0.5)	17.51 (± 0.8)	17.60 (± 0.5)	17.11 (± 0.8) [a]

Note: Values are expressed as mean ± *SD*.
[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers for each leg

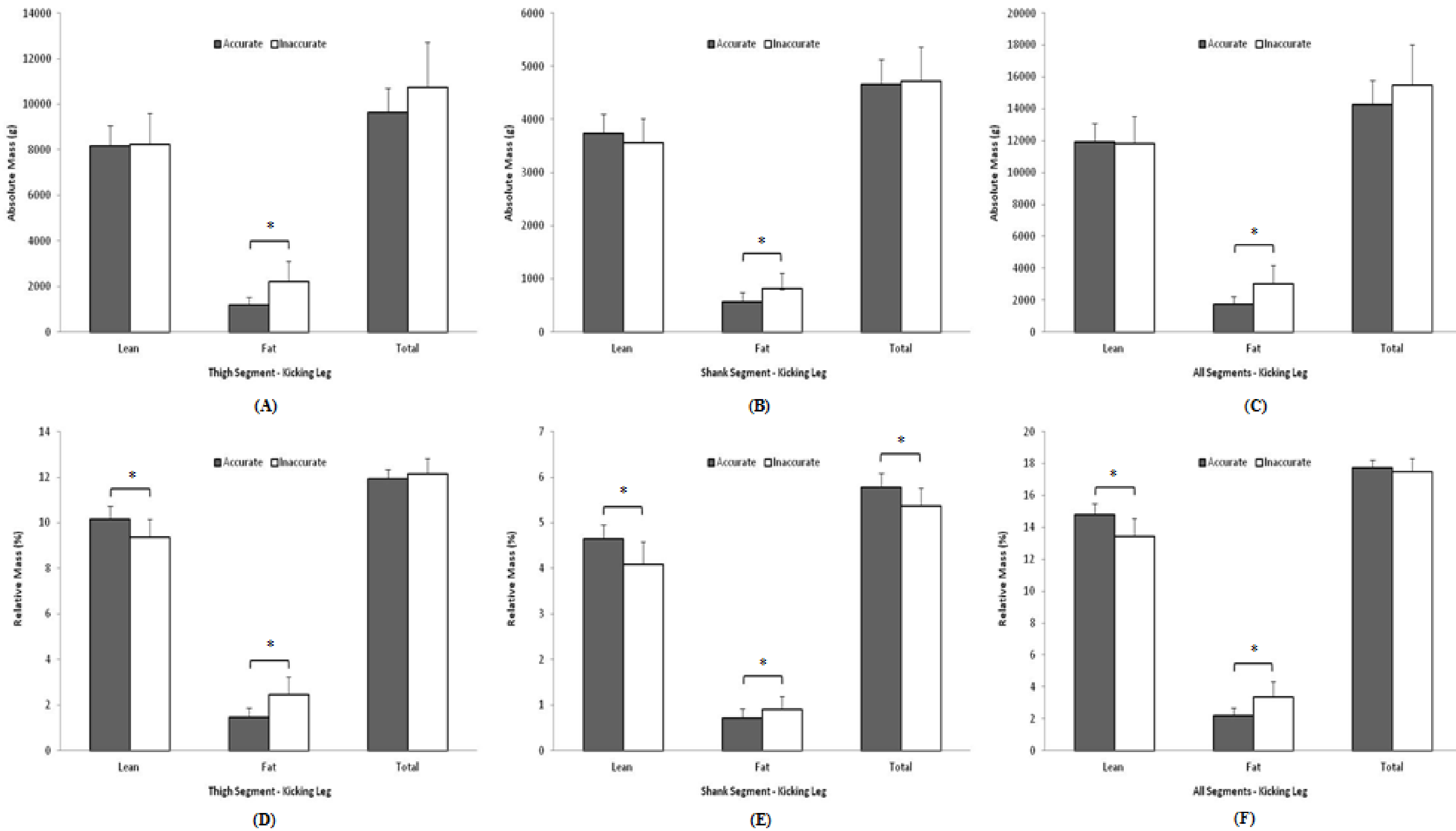


Figure 3. A comparison of the absolute thigh mass (A), shank mass (B), leg mass (C), and relative thigh mass (D), shank mass (E) leg mass (F) for lean, fat and total kicking leg composition between accurate and inaccurate kicking groups. Statistical significance (*) was set at $p \leq 0.05$.

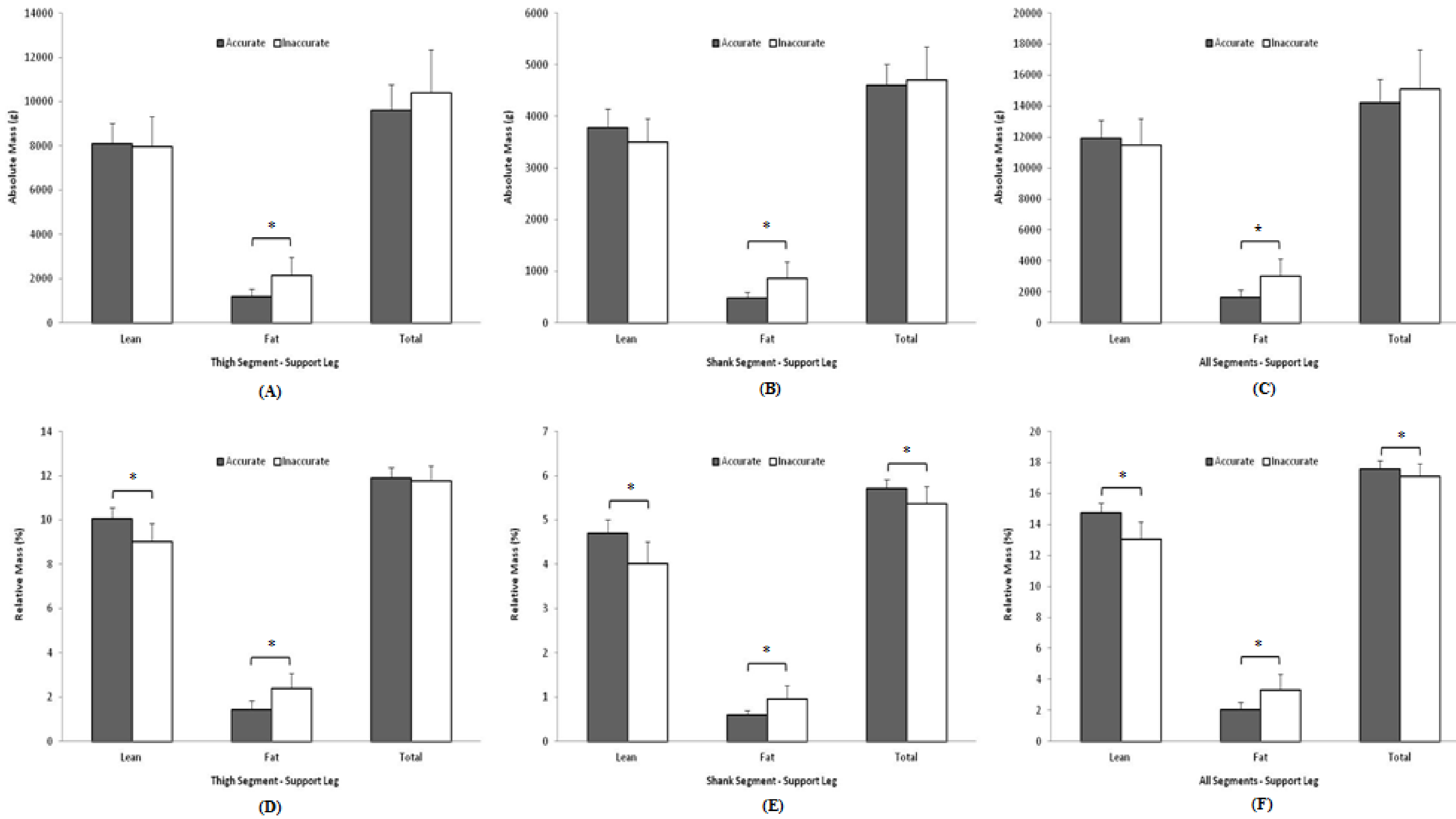
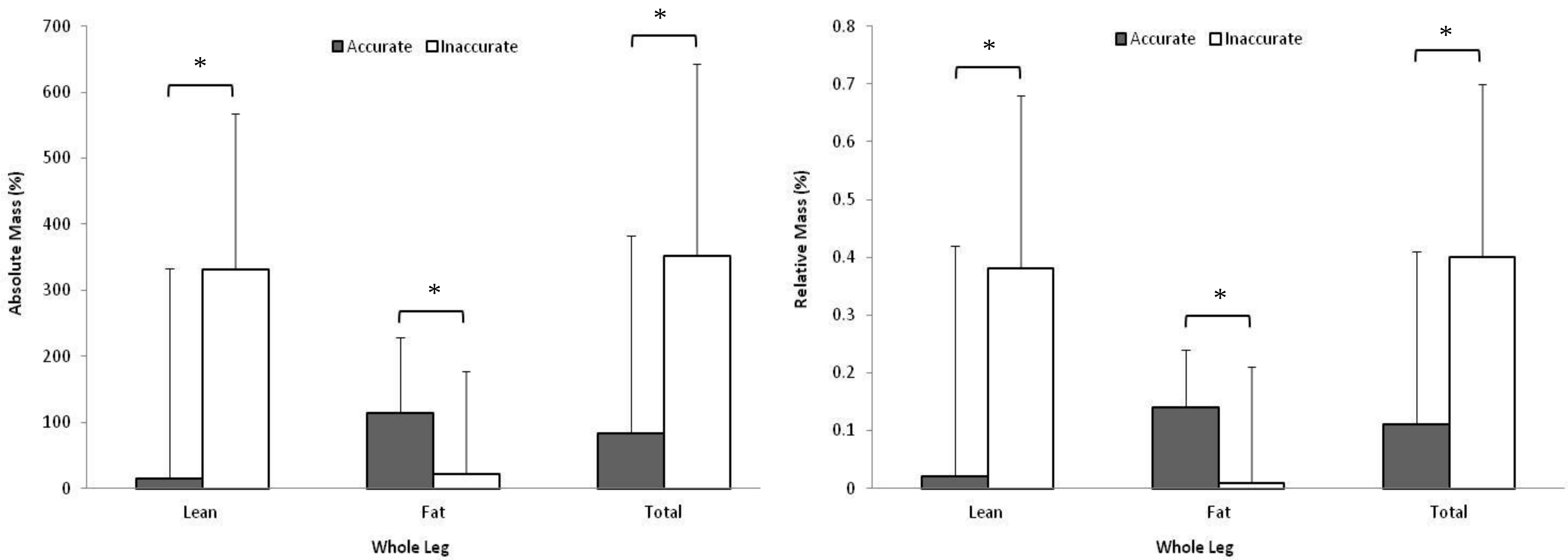


Figure 4. A comparison of the absolute thigh mass (A), shank mass (B), leg mass (C), and relative thigh mass (D), shank mass (E) leg mass (F) for lean, fat and total support leg composition between accurate and inaccurate kicking groups. Statistical significance (*) was set at $p \leq 0.05$.

Table 4. Correlation coefficients assessing the strength of relationship between leg mass characteristics and total kicking accuracy scores achieved by all kickers.

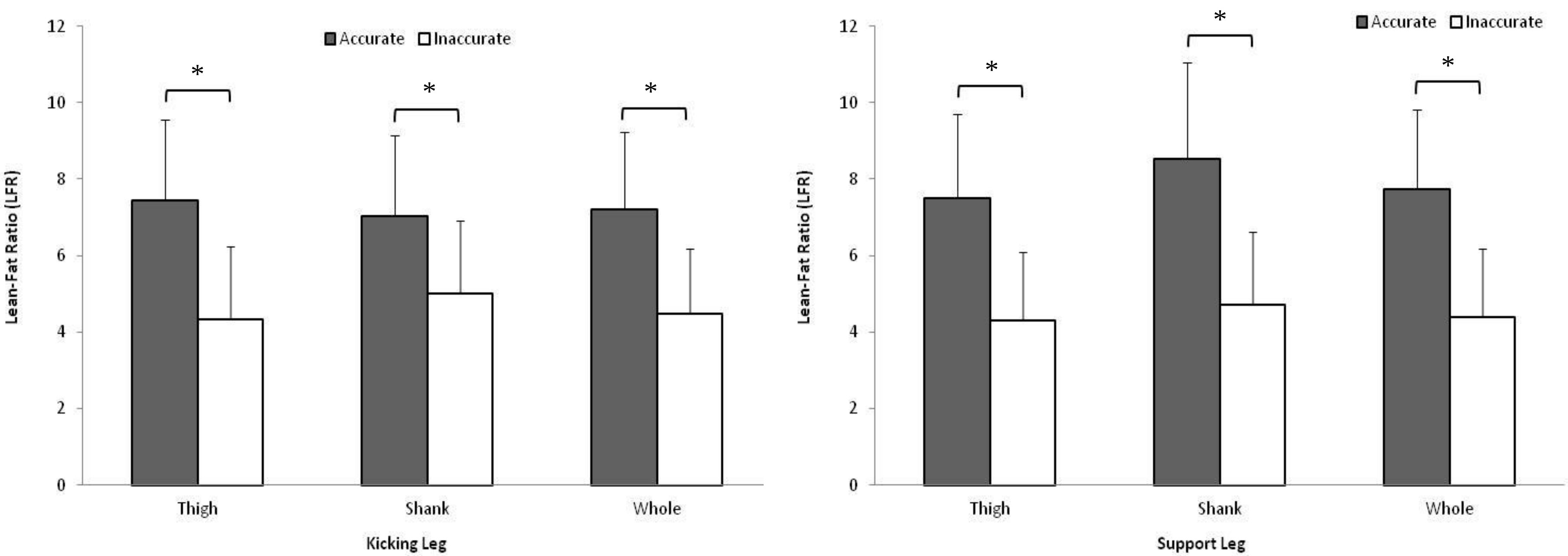
	Kicking Thigh	Kicking Shank	Kicking Leg	Support Thigh	Support Shank	Support Leg
Absolute Mass						
- Lean (g)	r = -0.008	r = -0.009	r = -0.009	r = 0.070	r = 0.073	r = 0.077
- Fat (g)	r = -0.559 [b]	r = -0.471 [c]	r = -0.552 [b]	r = -0.564 [b]	r = -0.557 [b]	r = -0.569 [b]
- Total (g)	r = -0.296	r = -0.250	r = -0.295	r = -0.223	r = -0.287	r = -0.248
Relative Mass						
- Lean (%)	r = 0.631 [b]	r = 0.462 [c]	r = 0.631 [b]	r = 0.694 [a]	r = 0.492 [b]	r = 0.698 [a]
- Fat (%)	r = -0.580 [b]	r = -0.431 [c]	r = -0.569 [b]	r = -0.585 [b]	r = -0.534 [b]	r = -0.582 [b]
- Total (%)	r = 0.085	r = 0.344 [c]	r = 0.279	r = 0.305 [c]	r = 0.285	r = 0.433 [c]

[a] Very strong effect - ($r \geq 0.7$).
[b] Strong effect - ($r \geq 0.5$).
[c] Moderate effect - ($r \geq 0.3$).



(A) **(B)**

Figure 5. A comparison of the composite mass imbalance [kicking leg – support leg] between (A) absolute and (B) relative leg mass components between accurate and inaccurate kickers. Statistical significance (*) was set at $p \leq 0.05$.



(A) **(B)**

Figure 6. A comparison of the lean-mass ratio of kicking (A) and support (B) legs. Statistical significance (*) was set at $p \leq 0.05$.

The lean-to-fat ratio (LFR) was significantly different (p = 0.001 to 0.009) for all segments across both limbs, demonstrating vastly higher quantities of lean mass relative to fat mass within accurate kickers. Furthermore, when comparing the residual difference of composite mass between limbs, inaccurate kickers exhibited significant larger imbalances in absolute and relative lean and total mass characteristics, favouring their kicking leg when compared to accurate kickers (p = 0.005 to 0.028). This was further illustrated by the lean mass imbalance (kicking leg divided by support leg), with accurate kickers showing no imbalance versus inaccurate kickers showing a significant imbalance (p = 0.002).

Correlation coefficients (*r*) between leg mass characteristics and subsequent kicking accuracy ratings are presented in Table 4. Positive correlations were noted between kicking accuracy scores and relative magnitudes of lean mass for both kicking (*r* = 0.462 to 0.631) and support (*r* = 0.492 to 0.698) limbs, exhibiting moderate to very strong positive relationships. Conversely, negative correlations were noted between kicking accuracy scores and relative magnitudes of fat mass within both kicking (*r* = -0.431 to -0.580) and support (*r* = -0.534 to -0.585) limbs, producing moderate to strong negative relationships. Furthermore, absolute fat mass across all segments of the kicking leg also produced moderate to strong negative correlations with kicking accuracy (*r* = -0.471 to -0.559). The lean-fat ratio further provided moderate-to-large positive correlations with kicking accuracy outcomes in both kicking (*r* = 0.482 to 0.606) and support (*r* = 0.554 to 0.622) limbs.

5.4. Discussion

The results of this study provide support for the hypothesis that successful athletes exhibit considerably different physical characteristics to their less successful counterparts (Nevill et al, 2009). Specifically, in this study, accurate kickers contained noticeably different leg mass characteristics than inaccurate kickers across all segments of the kicking and support limbs, particularly when expressed relative to total body mass. Similar amounts of total leg mass were evident between accurate and inaccurate kickers; however the composition of each segment and whole limb vastly differed between the groups with more accurate athletes exhibiting greater quantities of lean muscle mass and lower quantities of fat mass when expressed relative to total body mass.

While few studies have reported whole body composition and leg mass data using DEXA technology to profile and compare athletic populations (Veale et al, 2010; Andreoli et al, 2001), a multitude of research using a variety of body composition and lower limb estimation techniques are in agreement with the current study (Malina & Geithner, 2011; Veale et al, 2010; Ooi et al, 2009; Hoshikawa et al, 2009; Andreoli et al, 2001). In particular, the general conclusion drawn from this body of literature illustrates the positive relationship evident between greater absolute lean mass and athletic success across a broad range of sports (Malina & Geithner, 2011; Chaouachi et al, 2009; Bioleau & Lohman, 1977). However, the results of the present study further extend this positive relationship to also include relative quantities of lean mass.

Specifically, relative lean mass provided the largest difference between accurate and inaccurate kickers when expressed relative to total body mass, and as a ratio within individual segments (lean-to-fat ratio), while also producing the strongest correlations with kicking accuracy ratings. This appears logical, as the primary component of lean tissue is skeletal muscle mass; an active, contractile, force generating tissue which functionally contributes to skilful movement, and is proportionate to body size (Malina & Geithner, 2011; Hoshikawa et al, 2009; Loucks, 2004; Andreoli et al, 2001). This may also explain a functional limitation within the support leg of inaccurate kickers, which contained significantly less absolute and relative lean tissue mass in comparison to the kicking leg. As force generation is related to muscle size, and intrinsic contractile properties (Hoshikawa et al, 2009; Perez-Gomez et al, 2008; Andersen & Aagaard, 2006), the inferiority of lean mass within the support leg of inaccurate kickers may create a physical weakness. In particular, a reduced strength capacity in response to lower muscle mass within the support leg may have negative implications towards the effective stabilisation and controlled execution of the kicking skill within inaccurate kickers which requires further investigation.

Furthermore, previous research has not yet reported absolute or relative quantities of fat mass within athletic populations across the entire body. As excessive fat mass impacts negatively on sports requiring the projection of a body through space (Malina & Geithner, 2011; Nevill et al, 2009), the magnitude and distribution of this inert tissue requires acknowledgement and consideration (Loucks, 2004). In particular, the results of the present study support this proposition, demonstrating a clearly negative association between fat mass quantities in all lower limb segments with subsequent kicking performance. While the modification of leg mass characteristics in favour of greater lean tissue, and reduced fat tissue appears critically important to performance, it is worthwhile to note that these physical characteristics, while desirable, do not necessarily create accuracy; rather, they provide the athlete with an optimal foundation to achieve technical proficiency (Manolopoulos, Papadopoulos & Kellis, 2006). Given that the kicking action is complex and multidimensional, and requires the successful integration of whole body interactions to produce a desirable outcome (Shan & Westerhoff, 2005), potential confounding factors exist; particularly as kinematic strategies, kinetic profiles and muscle activation patterns were not assessed. Furthermore, this study was limited by the indoor laboratory environment and specific footwear used during testing which might have modified the quality of performance

Despite these limitations, the composite differences between accurate and inaccurate kickers in this study continue to pose some interesting questions for future research to address. In particular, 1) Will increasing total (absolute) mass of the kicking leg optimise the speed-accuracy trade-off? 2) Does greater relative lean mass enable heightened precision due to reduced volitional effort? 3) Will an increase in the lean-to-fat ratio adjust collision rigidity of the kicking shank (coefficient of restitution) during ball impact in favour of greater limb control? 4) Will increasing lean mass of the lower limbs enhance athletic stability during the technical components of the kicking action? and 5) Does a lean mass imbalance between kicking and support limbs create destabilisation during task execution? Addressing these questions will provide a more comprehensive overview of the physical characteristics underpinning skilful performance and kicking accuracy.

In conclusion, the findings of this study demonstrate that segmental mass characteristics differ between accurate and inaccurate Australian footballers performing the drop punt kick. This demonstrates an association between segmental mass characteristics may influence the technical proficiency and movement efficiency of common sporting skills, such as kicking. Furthermore, relative lean mass may provide an additional and more appropriate descriptor of athletic conditioning, particularly within sports which are limited by total body mass requirements. Future research aiming to profile athletes are encouraged to assess and report absolute and relative mass characteristics across the whole body, inclusive of individual appendicular segments.

5.5. References

Amiri-Khorasani, M., Osman, N. A. A., & Yusof, A. (2010). Kinematics Analysis: Number of trials necessary to achieve performance stability during soccer instep kicking. *Journal of Human Kinetics, 23*, 15-20.

Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology*, *96*(1), 46-52.

Andreoli, A., Monteleone, M., Van Loan, M., Promenzio, L., Tarantino, U., & De Lorenzo, A. (2001). Effects of different sports on bone density and muscle mass in highly trained athletes. *Medicine and Science in Sports and Exercise, 33*(4), 507-511.

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics*, *7*(1), 10-23.

Bioleau, R. A., & Lohman, T. H. (1977). The measurement of human physique and its effects on physical performance. *Orthopedic Clinics of North America, 8*, 563-581.

Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N. B., Cronin, J., & Chamari, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. *Journal of Sports Sciences*, *27*(2), 151-157.

Dichiera, A., Webster, K. E., Kuilboer, L., Morris, M. E., Bach, T. M., & Feller, J. A. (2006). Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. *Journal of Science and Medicine in Sport*, *9*(4), 292-298.

Hologic. (2004). QDR for Windows XP Reference Manual: Hologic Inc.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Hoshikawa, Y., Iida, T., Muramatsu, M., Nakajima, Y., Fukunaga, T., & Kanehisa, H. (2009). Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *Journal of Sports Sciences*, *27*(2), 129-138.

Keogh, J. (1999). The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *Journal of Science and Medicine in Sport*, *2*(2), 125-133.

Loucks, A. B. (2004). Energy balance and body composition in sports and exercise. *Journal of Sports Sciences*, *22*(1), 1-14.

Malina, R., & Geithner, C. (2011). Body composition of young athletes. *American Journal of Lifestyle Medicine*, *5*(3), 262-278.

Manolopoulos, E., Papadopoulos, C., & Kellis, E. (2006). Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scandinavian Journal of Medicine and Science in Sports*, *16*(2), 102-110.

Nevill, A., Holder, R., & Watts, A. (2009). The changing shape of "successful" professional footballers. *Journal of Sports Sciences, 27*(5), 419-426.

Ooi, C. H., Tan, A., Ahmad, A., Kwong, K. W., Sompong, R., Ghazali, K. A., et al. (2009). Physiological characteristics of elite and sub-elite badminton players. *Journal of Sports Sciences, 27*(14), 1591-1599.

Orchard, J., Walt, S., McIntosh, A., & Garlick, D. (1999). Muscle activity during the drop punt kick. *Journal of Sports Sciences, 17*(10), 837-838.

Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., et al. (2010). Strength and functional characteristics of men and women 65 years and older. *Rejuvenation Research, 13*(1), 75-82.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1-2), 143-150.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.

Shan, G., & Westerhoff, P. (2005). Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. *Sports Biomechanics*, *4*(1), 59-72.

Veale, J. P., Pearce, A. J., Buttifant, D., & Carlson, J. S. (2010). Anthropometric profiling of elite junior and senior Australian football players. *International Journal of Sports Physiology and Performance, 5*(4), 509-520.

Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement* (2nd ed.). Toronto: John Wiley & Sons, Inc.

Young, W., Gulli, R., Rath, D., Russell, A., O'Brien, B., & Harvey, J. (2010). Acute effect of exercise on kicking accuracy in elite Australian football players. *Journal of Science and Medicine in Sport, 13*(1), 85-89.

Young, W. B., Newton, R. U., Doyle, T. L., Chapman, D., Cormack, S., Stewart, G., et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules Football: a case study. *Journal of Science and Medicine in Sport, 8*(3), 333-345.

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118.

Young, W. B., & Rath, D. A. (2011). Enhancing Foot Velocity in Football Kicking: The Role of Strength Training. *Journal of Strength and Conditioning Research, 25*(2), 561-566.

CHAPTER SIX – STUDY FOUR

THE INFLUENCE OF LIMB MASS AND FOOT VELOCITY ON KICKING ACCURACY IN AUSTRALIAN FOOTBALL.

JOURNAL OF MOTOR BEHAVIOR
(IN REVIEW, JULY 2012).

Nicolas H. Hart, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton

6.0. Abstract

In football sports', kicking a ball accurately over a desired distance to an intended target is arguably the most important skill to acquire, therefore understanding the potential mechanisms which underpin kicking accuracy is important. For example, increasing leg mass to enable a proportionately lower angular velocity might successfully exploit the speed-accuracy trade-off in favour of greater accuracy. The aim of this paper was to assess the influence of leg mass and foot velocity on kicking accuracy in Australian Football. Thirty-one Australian footballers were recruited to perform ten drop punt kicks over twenty metres to a player target. Athletes were separated into accurate (n = 15) and inaccurate (n = 16) kicking groups, with leg mass characteristics assessed using whole body DEXA scans, and foot velocity determined using a ten-camera Vicon motion capture system. Results demonstrated no relationship between foot velocity and kicking accuracy (r = -0.047 to -0.083). Relative lean mass was positively correlated with kicking accuracy (r = 0.631), with interactions between leg mass and foot velocity only evident within accurate kickers (r = -0.670 to -0.701). Given the potential importance of lean mass, and its interaction with foot velocity within accurate kickers; future research may wish to directly explore the speed-accuracy and impulse-variability constructs using controlled, with-in subject, resistance training and skill acquisition studies as possible pathways to heightening kicking accuracy.

6.1. Introduction

Football sports require a combination of speed and accuracy in various forms in order to generate a successful performance; however the act of kicking a ball accurately to a specified target is arguably the most important skill to master (Ball, 2007b). Any kicker who is able to deliver a ball accurately over greater maximal and sub-maximal distances becomes a more critical asset to their team (Young & Rath, 2011; Young et al, 2010; Ball, 2008), particularly as the effectiveness of the kicking skill can often differentiate between winning or losing a competitive match (Ball, 2007a; Dichiera et al, 2006). Despite the importance of kicking accuracy in sport, limited attention has been provided in the literature to investigate ways to describe, develop and improve this technical characteristic (Young et al, 2010; Dichiera et al, 2006).

Previous research has identified a variety of ways to enhance kicking distance (Young & Rath, 2011; Baktash, Hy, Muir, Walton & Zhang, 2009; Ball, 2008; Ball, 2007a), principally focusing attention towards the optimisation of foot velocity as a direct and comprehensive descriptor for subsequent ball velocity (Ball, 2008; Kellis & Katis, 2007; Lees & Nolan, 1998; Levanon & Dapena, 1998). However, foot velocity might not resonate strongly with kicking accuracy intentions. In particular, resultant ball velocity is the product of applied angular impulse and transferred angular momentum (Baktash et al, 2009; Sterzing & Hennig, 2008); and while foot velocity is an influential characteristic of kicking behaviour, it does not wholly represent the complexity of the kicking action. Specifically, it fails to address the fundamental description of angular momentum which requires the consideration of both the quantity and distribution of lower limb mass, in addition to the angular foot velocity produced at ball impact (Baktash et al, 2009; Andersen, Dorge & Thomsen, 1999; Lees & Nolan, 1998).

Therefore, to modify kicking behaviour, an athlete may adjust the speed (angular velocity) at which the limb travels, or alternatively adjust the striking mass (rotational inertia) of the limb itself (Young & Rath, 2011; Ball, 2008; Kellis & Katis, 2007). While increasing the velocity of the kicking limb might improve kicking distance, there is a potential conflict with kicking accuracy due to an anticipated speed-accuracy trade-off (Nagengast, Braun & Wolpert, 2011; Beilock, Bertenthal, Hoerger & Carr, 2008; Magill, 2008), prompting a possible decrease in movement precision at higher limb velocities (Urbin, Stodden, Fischman & Weimar, 2011; Dean & Maloney, 2007). Instead, a plausible solution may involve the positive manipulation of striking mass, as this should allow an equivalent distance to be achieved at a reduced angular velocity (Young & Rath, 2011), effectively shifting the speed-accuracy continuum towards greater accuracy without compromising achievable distance. This might honour both distance and accuracy intentions, though is yet to be scientifically confirmed.

A paucity of research exists investigating the potential relationship between the technical and temporal strategy of accurate and inaccurate kickers in response to the physical parameters modifiable by athletic conditioning. Extending the literature to heighten the scientific understanding of those mechanisms which underpin accurate performance will inevitably improve the quality of coaching, physical conditioning and acquisition strategies, with the express aim to enhance athletic performance. In particular, adjusting the quality (composition) and quantity (amount) of lower limb mass may have a profound impact on an athlete's kicking action and technical proficiency. It is therefore the purpose of this paper to investigate the influence and interrelationships of leg mass characteristics and foot velocity production on kicking accuracy outcomes between accurate and inaccurate kickers; to serve as a hypothesis-generating study (Bishop, 2008) for future intervention-based, longitudinal research investigations.

6.2. Methods

6.2.1. Subjects

Thirty-one Australian footballers (age: 22.1 ± 2.8 yrs; mass: 85.1 ± 13.0 kg; height: 181.1 ± 7.0 cm; BMI: 25.9 ± 3.2) were recruited from the Western Australian Football League (WAFL) for participation in this study. All athletes were required to have a minimum of five years total playing experience, with two consecutive years of experience at their current playing level. Athletes were also required to have no injuries or contraindications at the time of testing; and were not permitted to perform any strenuous exercise or lower body resistance training within 48 hours of their assigned testing session. All athletes were notified of the potential risks involved, and provided written informed consent for participation. Ethics clearance was provided by Edith Cowan University's Human Ethics Committee.

6.2.2. Study Design

This study utilised an acute, between-groups, cross-sectional design, consisting of a single testing session. Sessions commenced with anthropometric measures including height, weight, joint breadths and limb lengths; followed by an assessment of whole-body composition and lower body segmental mass characteristics (lean, fat, total) of the kicking and support limbs using dual energy x-ray absorptiometry (DEXA). Athletes were taken through a general dynamic warm-up, prior to a sport-specific warm-up (kicking over variable distances), designed to stabilise their kicking performance (Amiri-Khorasani, Osman & Yusof, 2010). The kicking protocol consisting of ten drop punt kicks over 20 metres was then completed. Athletes were required to wear their club issued football shorts; were provided with indoor football shoes (Nike5 Bomba, Nike Inc, USA); and were thoroughly familiarised with all testing procedures prior to official assessment. Following the assessment and analysis of their kicking performance, subjects were subsequently assigned to accurate (n = 15) and inaccurate (n = 16) groups for further analysis (Table 1), in accordance with accuracy determination criteria.

Table 1. Subject characteristics for accurate and inaccurate groups.

Subject Characteristics	**Accurate Kickers**	**Inaccurate Kickers**
Age (yrs)	21.7 (± 3.3)	23.1 (± 1.9)
Height (cm)	181.7 (± 6.7)	180.8 (± 7.3)
Weight (kg)	80.6 (± 8.0)	89.4 (± 15.2) [a]
Kicking Leg Length (cm)	87.3 (± 3.3)	85.7 (± 3.6)
Body Mass Index (BMI)	24.4 (± 1.5)	27.3 (± 3.8) [a]
Total Body Fat (%)	11.1 (± 2.0)	17.4 (± 5.2) [a]
Kicking Accuracy (%)	91.3 (± 11.3)	57.5 (± 16.4) [a]
Peak Foot Velocity (deg/s)	1156.2 (± 271.1)	1165.1 (± 133.9)

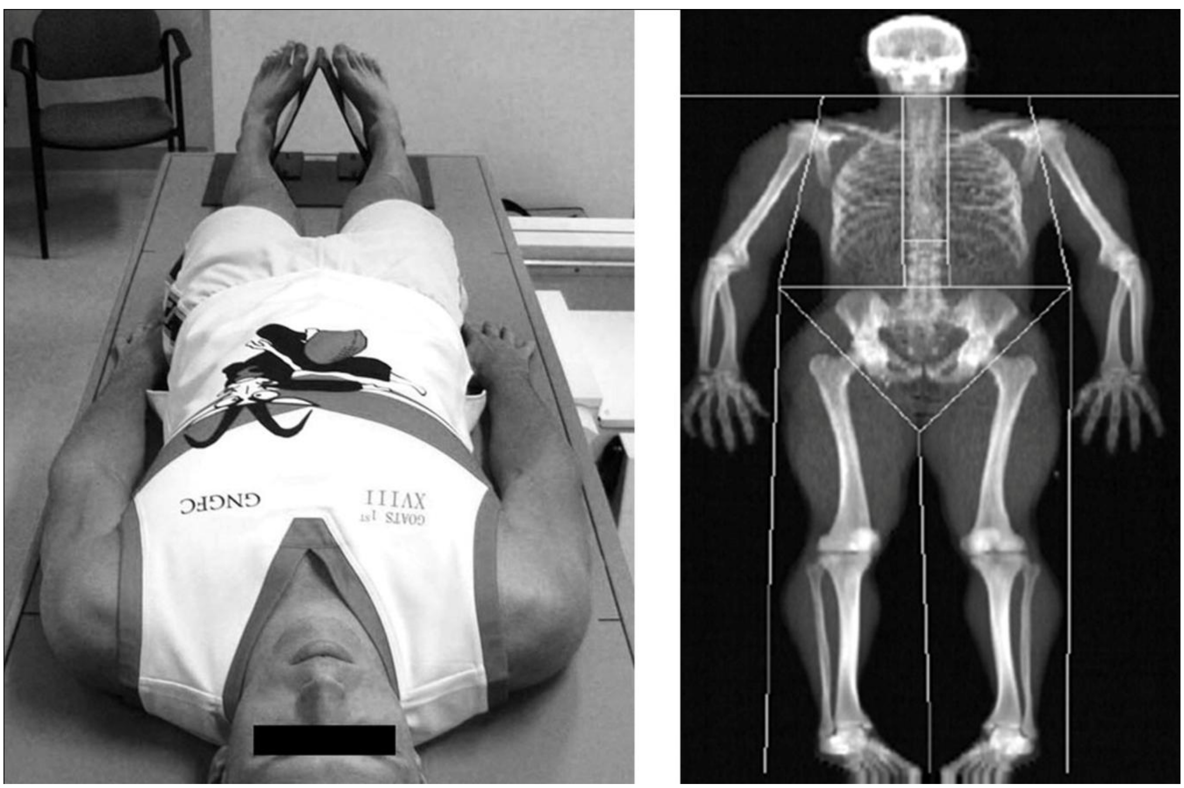
Note: Values are expressed as mean ± *SD.*

[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.

6.2.3. Scan Procedure

Lower limb mass and full-body composition components were assessed with dual energy x-ray absorptiometry (DEXA; Hologic Discovery A, Waltham, WA) using previously established, standardised and reliable body positioning and scan analysis procedures

(Hologic, 2004; Peiffer et al, 2010). Subjects assumed a stationary, supine position on the scanning bed with both arms pronated by their side, and hands facing the table. To ensure consistent body positioning, the DEXA operator manually assisted subjects in order to straighten their head, torso and pelvis; internally rotate and fixate their legs and feet at 45°; and ensured they were located within the DEXA scanning zone (Figure 1a). This has been shown to produce a scan/re-scan coefficient of variation below 1% (Peiffer et al, 2010). Standing height was recorded to the nearest 0.1 centimetre using a wall-mounted stadiometer, with body mass recorded to the nearest 0.1 kilogram using a standard electronic weighing scale.



(A) **(B)**

Figure 1. The DEXA scan and analysis process, with (A) a frontal view of the subject positioning process, illustrating pronated arms, and internally rotated thighs using a positioning device; and (B) the whole body analysis zones used to define the lower limbs.

6.2.4. Scan Analysis

Whole body scans were analysed using the inbuilt analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, WA). The predefined, mandatory whole body model (Hologic, 2004) was applied to the scan image, separating the body into axial and appendicular sections to determine whole body composition and segmental composition of the kicking and support legs. Composite mass outputs were categorised into fat mass (g), lean mass (g) and total mass (g) values for each sub-region across all scans and subjects using Microsoft Excel (Microsoft, Redmond, WA). Relative lean mass for each limb was calculated by dividing the amount segmental mass (g) by total body mass (g).

6.2.5. Foot Velocity

Three-dimensional motion analysis of the kicking action was assessed using a ten-camera optoelectronic device (ViconMX, Vicon, Oxford, UK), sampling at 250 Hz. A previously validated full body model was used to capture the movement patterns produced, with 39 retroreflective markers positioned on subjects, over specific anatomical landmarks in accordance with the Vicon Plug-in Gait model. A series of anthropometric measures were also required to fulfil this model, including joint breadths of the both elbows, wrists, knees and ankles; as well as leg length of both lower limbs, as defined by the Plug-In Gait model. Retroreflective markers were positioned on the athlete prior to their sports-specific kicking based warm-up to allow adequate familiarisation of kicking with markers attached. Official trials were recorded using the inbuilt data acquisition software (ViconNEXUS, 1.7.1; Vicon, Oxford, UK). Although peak foot velocity was the only kinematic variable assessed and required by this study; the full-body model was applied as part of a larger collection procedure which extends further than the scope of the current paper.

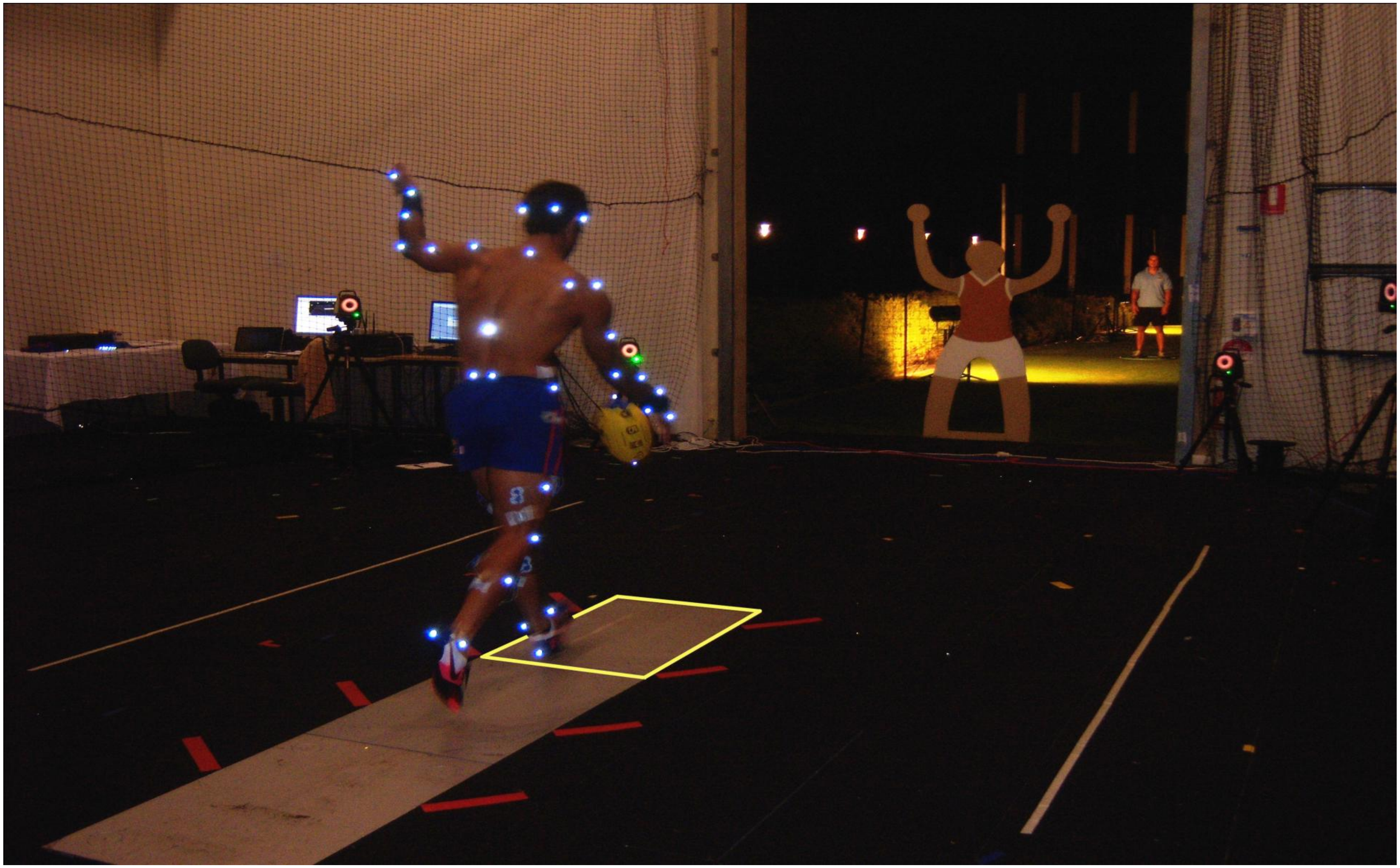


Figure 2. The kicking protocol set-up, with the athlete performing the drop punt, over an obstacle (height: 6 ft), to a stationary human target 20 metres from the kicking zone (outlined, dimensions: 1.0m x 0.7m).

6.2.6. Kicking Protocol

Kicking technique was assessed using the drop punt kick, performed with an Australian football (450g, Sherrin, Victoria, AU) inflated to official air pressure specifications (67 – 75 kPa) (Ball, 2008), using an electronic air pump (Air Erupt, Volcano, Taiwan). Athletes were required to produce ten drop punt kicks to a stationary human (player) target situated 20 metres from the centre of the kicking zone with the intention to deliver the ball as accurately as possible to the specified target (Figure 2). The twenty meter distance was chosen to correspond with other kicking accuracy literature in Australian Football (Young et al, 2010; Dichiera et al, 2006), and to replicate game-based accuracy demands when kicking to another player, as short kicks are often used to deliver a ball to another player in Australian Football (Dichiera et al, 2006). A life-sized obstacle representing an opposite player (base-to-head height: 6 ft; base-to-hand height: 7 ft) was positioned between the kicker and their target to control for minimum kicking trajectory, and to increase game-test specificity in the laboratory environment as Australian Footballers are regularly required to kick a ball to another player over an opponent defending space on the field.

Prior to commencing the kicking protocol, subjects completed a series of mechanically specific warm-up sets (5 drop punt kicks over 20m, 30m and 40m respectively, totalling 15 warm-up trials). Their ten official drop punt trials were then completed with a one minute recovery provided between each kick. For the trial to be considered successful, the athlete had to produce an approach consisting of at least two steps prior to planting their foot within the assigned kicking zone. Any trials which did not meet this criterion were considered invalid, and a repeat kicking trial subsequently provided until ten successful kicks were produced. Angle of approach was not standardised.

6.2.7. Accuracy Analysis

Kicking accuracy was assessed using a customised numerical scoring system. All kicks were visually graded immediately following each trial by the lead researcher; the human target (receiving the ball) and a research assistant. All assigned scores were recorded and visually confirmed using a two-dimensional digital video camera (MV710I PAL, Canon, NSW, AU). The scoring system for each kick spanned from 1 (accurate), 2 (moderate) and 3 (inaccurate), and was judged by the location of ball delivery to the target (Table 2). Following ten successful kicks, each athlete's scores were summated, with total scores ranging between 10 to 30 points. Athletes were classified as either accurate (10 – 18 points) or inaccurate (19 – 30 points), resulting in fifteen accurate kickers, and sixteen inaccurate kickers. Kicking accuracy was subsequently determined by calculating the percentage of accurate trials produced within the ten trial quota.

Table 2. Accuracy grading and determination criteria for human target kicking outcomes.

Assigned Score	Description of Ball Delivery to Target
1 (Accurate)	The ball is delivered directly to the target, between the waist and head of the receiving player. The target should not reach or jump in any direction from their stationary position for this score to be awarded.
2 (Moderate)	The ball slightly deviates from the target, though not excessively (within the targets reach). The target may take one step or reach in any direction; jump directly upwards; or kneel down from their stationary position for this score to be awarded. No combined "step and reach" or "jump and reach" are allowed.
3 (Inaccurate)	The ball misses the target by any margin beyond the limits seen within the 'Accurate' or 'Moderate' grading criteria. If the target needs to step and reach; jump and reach; or take more than one step to receive the ball, or, if the ball misses the target zone all together; it is awarded an inaccurate score.

6.2.8. Statistical Analysis

Independent t-tests was used to determine whether significant differences were evident between subject characteristics, kicking leg mass components, and peak foot velocity produced by accurate and inaccurate kickers. Statistical significance was set at an alpha level of $p \leq 0.05$. Pearson's product moment (PPM) correlation coefficient (r) was calculated to determine the strength of relationship between leg mass variables to peak angular foot velocities; leg mass variables to kicking accuracy scores; and peak angular foot velocities to kicking accuracy scores. The strength of relationship was classified in accordance with Hopkins (2002): $r \geq 0.3$ is moderate; $r \geq 0.5$ is strong; $r \geq 0.7$ is very strong; $r \geq 0.9$ is nearly perfect; and $r \geq 1.0$ is perfect. All statistical computations were performed using a statistical analysis program (SPSS, Version 17.0; Chicago, IL).

6.3. Results

Table 3. Leg mass characteristics of the kicking limb for accurate and inaccurate kickers.

	Accurate Kickers	**Inaccurate Kickers**
Absolute Mass		
- Lean (g)	11913 (± 1170)	11806 (± 1720)
- Fat (g)	1764 (± 483)	3017 (± 1179) [a]
- Total (g)	14281 (± 1496)	15461 (± 2567)
Relative Mass		
- Lean (%)	14.79 (± 0.7)	13.44 (± 1.1) [a]
- Fat (%)	2.16 (± 0.5)	3.35 (± 1.0) [a]
- Total (%)	17.71 (± 0.5)	17.51 (± 0.8)

Note: Values are expressed as mean ± *SD*.
[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.

No significant differences between accurate and inaccurate kickers were visible for absolute lean mass and absolute total mass across all segments of the kicking leg, with only absolute fat mass reaching significance ($p \leq 0.001$), demonstrating lower fat mass in accurate kickers (Table 3). When expressed relative to body mass, a greater interaction between composite mass and kicking accuracy was observed. Relative lean mass was significantly higher ($p \leq 0.001$), and relative fat mass was significantly lower ($p \leq 0.001$) in accurate kickers. Furthermore, a strong positive correlation was evident between kicking accuracy and relative lean mass within the kicking leg (r = 0.631), with strong negative correlations shown between both absolute and relative quantities of fat mass within the kicking leg (r = -0.568 to -0.582). All correlation coefficients are presented in Table 4.

Table 4. Correlation coefficients between kicking accuracy and kicking leg mass.

	Lean (g)	**Fat (g)**	**Total (g)**
Absolute Mass	r = -0.009	r = -0.552 [b]	r = -0.295
Relative Mass	r = 0.631 [b]	r = -0.569 [b]	r = 0.279

[b] Strong effect ($r \geq 0.5$) between kicking accuracy and leg mass.

The relationship between peak foot velocity and the magnitude of absolute kicking leg mass (total, and lean) are presented in Figure 3. Specifically, absolute total mass of the kicking leg produced a moderate correlation when data was pooled (r = -0.399), a very strong negative correlation within the accurate group (r = -0.701), and no notable correlation within the inaccurate group (r = -0.274). Similarly, absolute lean mass of the kicking leg followed the same trend between groupings with coefficients of r = -0.421, r = -0.670 and r = -0.228 respectively. No significant correlations were visible between relative lean or relative total kicking leg mass with peak foot velocity (r = -0.199 to r = 0.284). Furthermore, no significant correlations were evident between foot velocity and kicking accuracy, with coefficients r = -0.047, r = -0.035 and r = -0.083 for the pooled (Figure 4), accurate and inaccurate groups respectively.

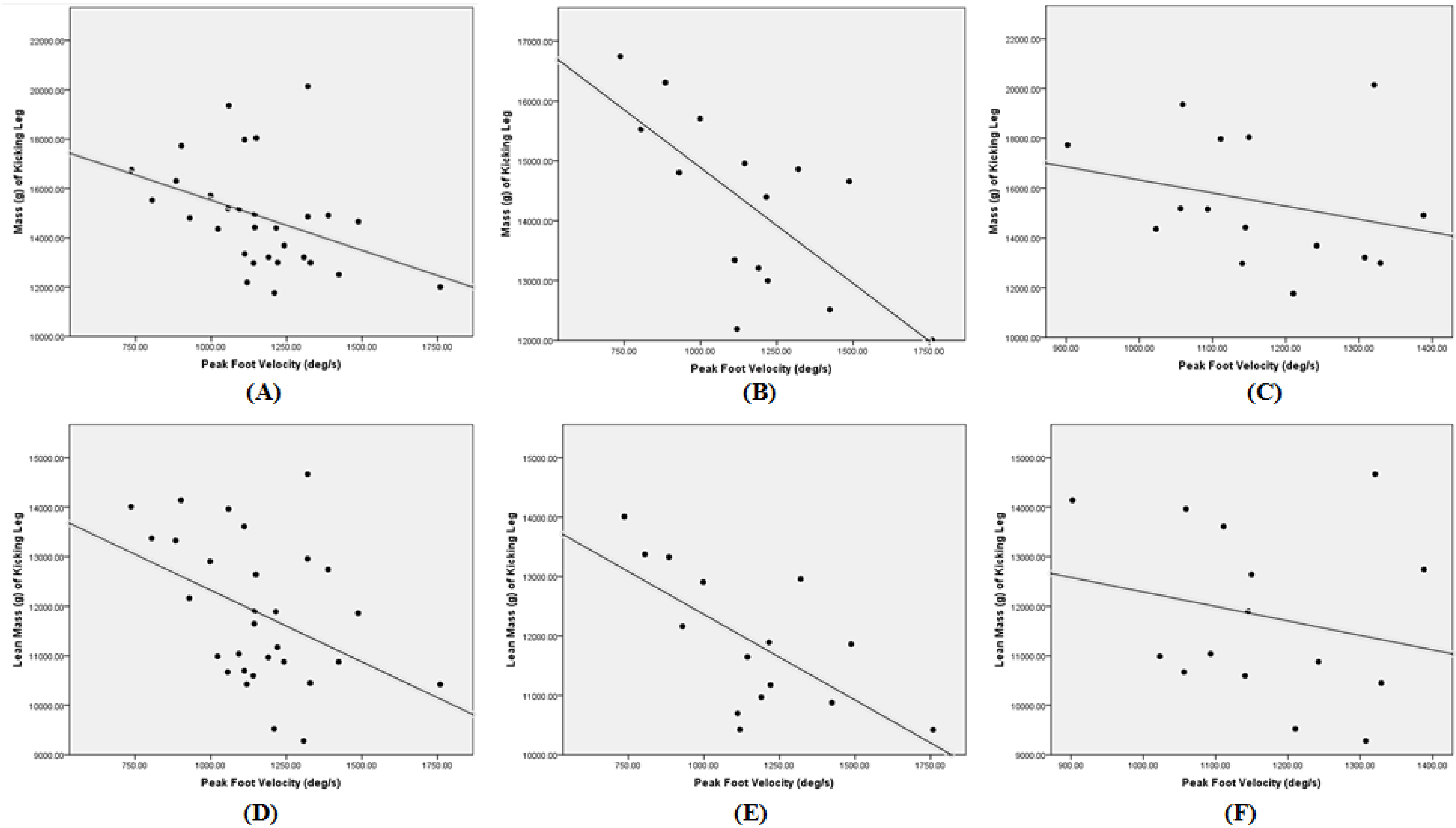


Figure 3. A correlational analysis between peak angular foot velocity and total mass of (A) pooled, (B) accurate, (C) inaccurate kickers; as well as lean mass of (D) pooled, (E) accurate, (F) inaccurate kickers.

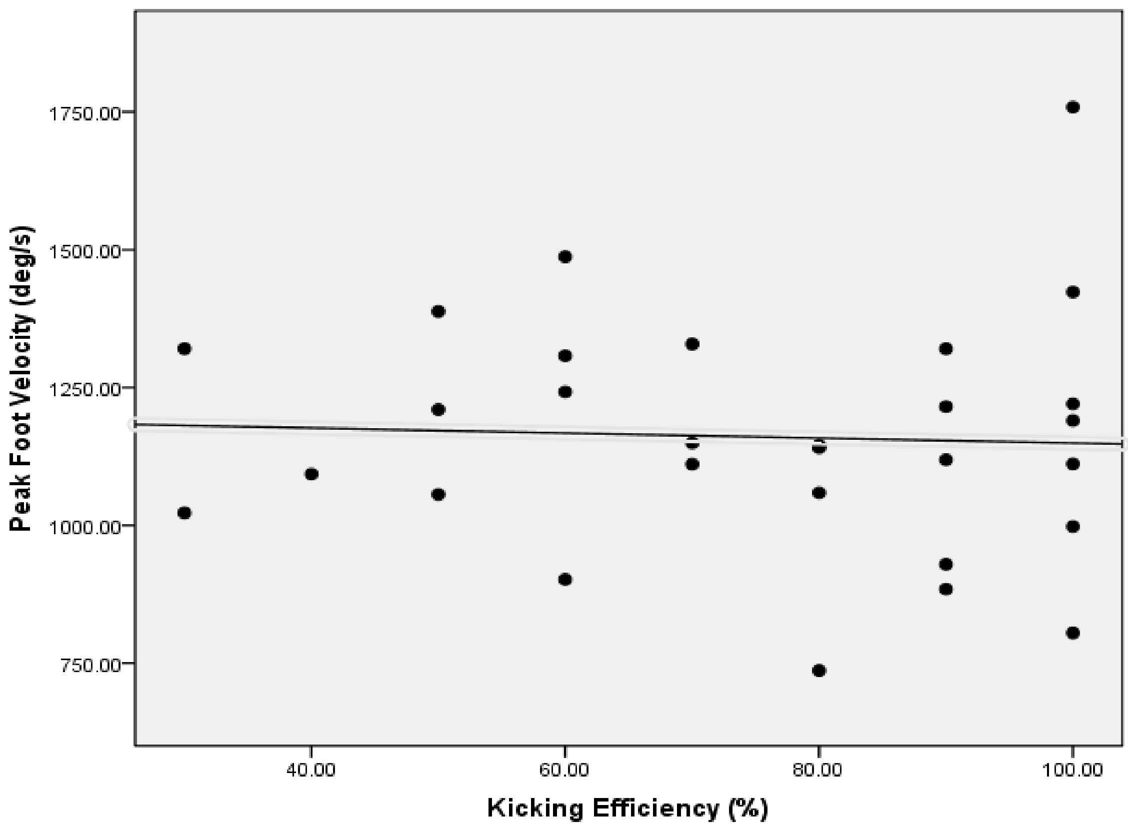


Figure 4. Correlation analysis between peak angular foot velocity and kicking accuracy.

6.4. Discussion

The purpose of this study was to investigate the influence and interrelationships of leg mass and foot velocity on kicking accuracy outcomes between accurate and inaccurate kickers in Australian Football. The results of this study demonstrated no interaction between peak foot velocity and kicking accuracy between-subjects; as accurate kickers with various limb mass characteristics produced vastly different angular foot velocities, ranging between 750 and 1750 degrees per second. Instead, accurate kickers contained significantly greater quantities of relative lean mass and significantly lower quantities of relative fat mass in their kicking leg, which might explain their ability to mediate and control foot velocity production in accordance with heightened limb co-ordination and control**.**

The absence of a relationship between limb velocity and target accuracy in the current study may be due to the between-subjects design utilised; however these results are also in agreement with recent literature investigating similar multi-joint dynamic, asymmetrical motor skills which utilised with-in subject study designs, including the tennis serve and ground-stroke (Landlinger et al, 2011; Cauraugh, Gabert & White, 1990), fast-bowling in cricket (Phillips, Portus, Davids & Renshaw, 2011), and shooting in handball (Van den Tillar & Ettema, 2003), finding no significant correlations with speed of movement and subsequent accuracy within skilled athletes. A potential explanation might include the quantity and structure of training provided to experienced athletes, who are specifically trained to perform accurately at high speeds (Wagner, Pfusterschmied, Klous, von Duvillard & Muller, 2012); therefore, speed of movement may not be a performance restriction in expert, elite performers (Nagengast et al, 2011; Phillips et al, 2011). Instead, other factors might be more influential within these populations, including mental strategy, movement variability, limb strength, and striking mass (Chelly, Hermassi & Shephard, 2010; Wilson, Simpson, van Emmerik, & Hamill, 2008; Schorer, Fath, Baker & Jaitner, 2007; Manolopoulos, Papadopolulos, & Kellis, 2006; Janelle, 2002); which are factors modifiable through training interventions and may assist with improving kicking accuracy.

Previous research investigating the interaction between movement speed and target accuracy have primarily assessed the speed of movement as an isolated entity, without equal consideration for the striking mass characteristics or proportionate muscular impulses required to produce the movement (Urbin et al, 2011; Schmidt & Lee, 2005). In Australian Football, the desired ball velocity required to reach an intended target cannot be wholly explained by foot velocity or lower limb mass in isolation; rather, it is the controlled co-

contribution of these two characteristics which appears to discriminate between the accurate and inaccurate performer, evidenced by the very strong inverse relationship within the accurate kicking group of this study. The ability of accurate kickers to readily mediate foot velocity as a product of their striking mass seems to suggest an element of superior spatial and temporal control often seen within expert performers (Wilson et al, 2008; Williams & Ericsson, 2005; Cameron & Adams, 2003; Davids, Lees & Burwitz, 2000). While expert and novice performers both exhibit higher levels of movement variability during motor performance; expert performers display an active and deliberate functional variability, whereas novice performers demonstrate a circumstantial random variability (Wagner et al, 2012; Schorer et al, 2007). Since foot velocity is a highly volatile kinematic characteristic in kicking, and lean mass is a stable yet trainable component of the lower limbs; increasing the functional (lean) mass of the kicking leg appears to provide a practical training method to increase accuracy outcomes, potentially creating greater functional variability and system flexibility within an athlete, to appropriately mediate foot velocity.

The impulse-variability theory might provide a mechanistic explanation towards distinguishing between accurate and inaccurate kickers (Urbin et al, 2011), In particular, the expected relationship between movement speed and target accuracy does not appear to acknowledge that any proportionate reduction in foot velocity to counterbalance greater leg mass would still require the same magnitude of muscular impulse to develop and transfer an equivalent angular momentum to the ball. This required impulse might be the critical component in accurate performance, as temporal and spatial components of limb behaviour (velocity, trajectory and distance) are a result of the magnitude and duration of muscular torques acting on the joint (Urbin et al, 2011; Magill, 2008). Specifically, reducing the relative muscular impulses required to produce the kicking action may improve kicking accuracy through greater limb control, potentially improving the compensatory movement variability of an athlete, thus increasing their ability to resist undesired perturbations at a proportionately reduced volitional effort (Phillips et al, 2011; Wagner et al, 2012; Wilson et al, 2008; Cameron & Adams, 2003). The results of this study appear to indirectly support this notion, with accurate kickers illustrating significantly greater relative lean mass, and significantly lower relative fat mass within their lower limbs, producing considerable correlations with kicking accuracy outcomes as a result.

There are, however, several limitations to this study which require acknowledgement. Limb co-ordination was not directly measured and was therefore inferred only; the cognitive component underlying skilled performance was not assessed; and total time spent training was not recorded; all of which are likely confounding factors in the context of our results. In conclusion, research investigating the speed-accuracy and impulse-variability relationships within familiar, asymmetrical, dynamic (acyclic) movement tasks remains limited; particularly for striking-based activities. Although this study utilised a between-subject design, it provides considerable insight into the interrelationship and influence of leg mass and foot velocity on kicking accuracy in Australian Football. In particular, this hypothesis-generating study provides a suitable premise for future research to directly explore the speed-accuracy and impulse-variability constructs using controlled, with-in subject, resistance training and skill acquisition studies. These future intervention-based research ventures might successfully illustrate greater relationships between the influence of individual leg mass modifications and their subsequent impact on individual kicking proficiency outcomes through engaging in practical training programs..

6.5. References

Amiri-Khorasani, M., Osman, N. A. A., & Yusof, A. (2010). Kinematics Analysis: Number of Trials Necessary to Achieve Performance Stability during Soccer Instep Kicking. *Journal of Human Kinetics, 23,* 15-20.

Andersen, T. B., Dorge, H. C., & Thomsen, F. I. (1999). Collisions in soccer kicking. *Sports Engineering, 2*, 121-125.

Baktash, S., Hy, A., Muir, S., Walton, T., & Zhang, Y. (2009). The effects of different instep foot positions on ball velocity in place kicking. *International Journal of Sports Science and Engineering, 3*(2), 85-92.

Ball, K. (2007a). Use of weighted balls for improving kicking for distance. *Journal of Sports Science and Medicine, 6*(Suppl. 10), 44.

Ball, K. (2007b). Foot-ball interaction in Australian Rules football. *Journal of Sports Science and Medicine, 6*(Suppl. 10), 46.

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics, 7*(1), 10-23.

Beilock, S., Bertenthal, B. I., Hoerger, M., & Carr, T. H. (2008). When does haste make waste? Speed-accuracy tradeoff, skill level, and the tools of the trade. *Journal of Experimental Psychology: Applied, 14*(4), 340-352.

Bishop, D. (2008). An applied research model for the sports sciences. *Sports Medicine, 38*(3), 253-263.

Cameron, M., & Adams, R. (2003). Kicking footedness and movement discrimination by elite Australian Rules footballers. *Journal of Science and Medicine in Sport, 6*(3), 266-274.

Cauraugh, J. H., Gabert, T. E., & White, J. J. (1990). Tennis serving velocity and accuracy. *Perceptual and Motor Skills, 70*, 719-722.

Chelly, M. S., Hermassi, S., & Shephard, R. J. (2010). Relationships between power and strength of the upper and lower limb muscles and throwing velocity in male handball players. *Journal of Strength and Conditioning Research, 24*(6), 1480-1487.

Davids, K., Lees, A., & Burwitz, L. (2000). Understanding and measuring coordination and control in kicking skills in soccer: implications for talent identification and skill acquisition. *Journal of Sports Sciences, 18*(9).

Dean, M., Wu, S. W., & Maloney, L. T. (2007). Trading off speed and accuracy in rapid, goal-directed movements. *Journal of Vision, 7*(5), 1-12.

Dichiera, A., Webster, K. E., Kuilboer, L., Morris, M. E., Bach, T. M., & Feller, J. A. (2006). Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. *Journal of Science and Medicine in Sport, 9*(4), 292-298.

Hologic. (2004). QDR for Windows XP Reference Manual: Hologic Inc.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Janelle, C. M. (2002). Anxiety, arousal and visual attention: a mechanistic account of performance variability. *Journal of Sports Sciences, 20*, 237-251.

Kellis, E., & Katis, A. (2007). Biomechanical Characteristics and Determinants of Instep Soccer Kick. *Journal of Sports Science and Medicine, 6*, 154-165.

Landlinger, J., Stoggl, T., Lindlinger, S., Wagner, H., & Muller, E. (2011). Differences in ball speed and accuracy of tennis groundstrokes between elite and high-performance players. *European Journal of Sport Science*, 1-8.

Lees, A., & Nolan, L. (1998). The biomechanics of soccer: a review. *Journal of Sports Sciences, 16*(3), 211-234.

Levanon, J., & Dapena, J. (1998). Comparison of the kinematics of the full-instep and pass kicks in soccer. *Medicine and Science in Sports and Exercise, 30*(6), 917-927.

Magill, R. (2008). *Motor Learning and Control: Concepts and applications* (8th ed.). New York, NY: McGraw-Hill.

Manolopoulos, E., Papadopoulos, C., & Kellis, E. (2006). Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scandinavian Journal of Medicine and Science in Sports, 16,* 102-110.

Nagengast, A. J., Braun, D. A., & Wolpert, D. M. (2011). Risk sensitivity in a motor task with speed-accuracy trade-off. *Journal of Neurophysiology, 105*(6), 2668-2674.

Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., et al. (2010). Strength and functional characteristics of men and women 65 years and older. *Rejuvenation Research, 13*(1), 75-82.

Phillips, E., Portus, M., Davids, K., & Renshaw, I. (2011). Performance accuracy and functional variability in elite and developing fast bowlers. *Journal of Science and Medicine in Sport*.

Schmidt, R., & Lee, T. (2005). *Motor Control and Learning: A behavioural emphasis* (4th ed.). Champaign, IL: Human Kinetics.

Schorer, J., Fath, F., Baker, J., & Jaitner, T. (2007). Identification of interindividual and intraindividual movement patterns in handball players of varying expertise levels. *Journal of Motor Behavior, 39*(5), 409-421.

Sterzing, T., & Hennig, E. M. (2008). The influence of soccer shoes on kicking velocity in full-instep kicks. *Exercise and Sport Sciences Reviews, 36*(2), 91-97.

Urbin, M. A., Stodden, D. F., Fischman, M. G., & Weimar, W. H. (2011). Impulse-variability theory: implications for ballistic, multijoint motor skill performance. *Journal of Motor Behavior, 43*(3), 275-283.

van den Tillaar, R., & Ettema, G. (2003). Instructions emphasizing velocity, accuracy, or both in performance and kinematics of overarm throwing by experienced team handball players. *Perceptual and Motor Skills, 97*(3 Pt 1), 731-742.

Wagner, H., Pfusterschmied, J., Klous, M., von Duvillard, S. P., & Muller, E. (2012). Movement variability and skill level of various throwing techniques. *Human Movement Science*, *31*(1), 79-90.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: some considerations when applying the expert performance approach. *Human Movement Science, 24*(3), 283-307.

Wilson, C., Simpson, S. E., van Emmerik, R. E., & Hamill, J. (2008). Coordination variability and skill development in expert triple jumpers. *Sports Biomechanics, 7*(1), 2-9.

Young, W., Gulli, R., Rath, D., Russell, A., O'Brien, B., & Harvey, J. (2010). Acute effect of exercise on kicking accuracy in elite Australian football players. *Journal of Science and Medicine in Sport, 13*(1), 85-89.

Young, W. B., & Rath, D. A. (2011). Enhancing Foot Velocity in Football Kicking: The Role of Strength Training. *Journal of Strength and Conditioning Research, 25*(2), 561-566

CHAPTER SEVEN – STUDY FIVE

DOES LOWER LIMB SYMMETRY ENHANCE TECHNICAL PROFICIENCY? A KICKING PERSPECTIVE.

JOURNAL OF SPORTS SCIENCES
(IN REVIEW, FEBRUARY 2012).

Nicolas H. Hart, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton

7.0. Abstract

Differential loading patterns experienced by athletes during game-based participation may produce or exacerbate strength imbalances between the lower limbs in the absence of suitable strength and conditioning programs. It is currently unknown whether such imbalances are functionally beneficial or detrimental to performance. The purpose of this paper was to assess the influence of lower limb symmetry on kicking accuracy in football. Thirty-one Australian footballers were recruited to perform ten drop punt kicks over twenty metres to a player target. Athletes were separated into accurate (n = 15) and inaccurate (n = 16) groups, with leg mass assessed using whole body DEXA scans, and leg strength assessed using an isometric back squat protocol. Accurate kickers were characteristically different to inaccurate kickers, with significantly higher lean mass ($p \leq 0.004$) and significantly lower fat mass ($p \leq 0.024$). Accurate kickers were absent of any significant strength imbalance or mass asymmetry in their lower limbs, whereas inaccurate kickers displayed a significant imbalance in strength ($p = 0.002$) and lean mass ($p \leq 0.029$), favouring their kicking leg, therefore showing a deficiency in their support leg. Greater lower limb symmetry could increase the capacity of an athlete to be technically proficient when performing the kicking skill, in favour of greater accuracy.

7.1. Introduction

Footballers require a high level of technical expertise and tactical awareness to successfully compete at the professional level, operating within a dynamic, fast-moving and volatile environment (Young & Pryor, 2007; Young et al, 2005). Their ability to produce a technically proficient performance relies upon a suitable foundation of athletic conditioning and muscular strength, often acquired through-out the systematic developmental pathways of their sport (Hoshikawa et al, 2009; Iga, George, Lees & Reilly, 2009). However, in the absence of sufficient physical development, the potential for an athlete to produce a skilful performance is substantially compromised. In particular, the differential loading patterns inherent within football sports, under training and competitive contexts, may produce or exacerbate strength imbalances within and between the lower limbs (Kubo, Muramatsu, Hoshikawa & Kanehisa, 2010; Newton et al, 2006; Cometti, Maffiuletti, Pousson, Chatard & Maffulli, 2000), potentially facilitating or diminishing performance outcomes.

In football sports, kicking is the most important and widely used skill (Ball, 2007; Saliba & Hrysomallis, 2001), routinely employed to deliver a ball accurately, over a desired distance, to an intended target or location, under a variety of different situational contexts (Ball, 2011; Young & Rath, 2011; Ball, 2008). However, due to the volatile nature of competitive play, footballers rarely engage their lower limbs with equal preference within the tactical realm of their sport, selectively utilising the dominant limb for most game-based activities (Ball, 2011; Zakas, 2006; Cameron & Adams, 2003). As the kicking skill places considerably different demands on the kicking and support limbs during task execution (Hides et al, 2010; Young & Rath, 2011; Baczkowski, Marks, Silberstein & Schneider-Kolsky, 2006; Nunome, Ikegami, Kozakai, Apriantono & Sano, 2006), the regularity of kicking performance may uniquely and specifically develop each limb preferentially for kicking and support purposes (Stewart, Stanton, Wilson & Hides, 2010; Gstottner et al, 2009; Hoshikawa et al, 2009; Newton et al, 2006; Kearns, Isokawa & Abe, 2001; Sadeghi, Allard, Prince & Labelle, 2000).

Previous research has attempted to identify whether a laterality effect exists within football, specifically profiling footballers at various stages of the development cycle, spanning the full junior-to-senior and recreational-to-professional athletic spectrum (Thorborg, Couppe, Petersen, Magnusson & Holmich, 2011; Hides et al, 2010; Kubo et al, 2010; Stewart et al, 2010; Veale, Pearce, Buttifant & Carlson, 2010; Hoshikawa et al, 2009; Iga et al, 2009; Zakas, 2006; Masuda, Kikuhara, Demura, Katsuta & Yamanaka, 2005; Rahnama, Lees & Bambaecichi, 2005; Masuda, Kikuhara, Takahashi & Yamanaka, 2003; Kearns et al, 2001; Saliba & Hrysomalis, 2001; McLean & Tumilty, 1993). However, a lack of consensus remains, with contrasting and contradictory outcomes evident across the research landscape. Given that some senior, elite footballers can have a visible limb imbalance (Thorborg et al, 2011; Hides et al, 2010; Stewart et al, 2010), while others can have no limb imbalance (Kubo et al, 2010; Hoshikawa et al, 2009; Zakas, 2006); there appears to be no definitive understanding as to whether the potential asymmetry of strength and muscularity in the lower limbs is favourable to performance, or undesirable to injury incidence (Newton et al, 2006; Criosier, Forthomme, Namurious, Van-derthommen & Crielaard, 2002; Theoharopoulos, Tsitskaris, Nikopoulou & Tskalis, 2000; Bennell et al, 1998; Orchard, Marsden, Lord & Garlick, 1997). Such discrepancies might be explained by the uncontrollable influence of different strength and conditioning programs underpinning the physical development of each cohort of athletes, in addition to the notable limitations inherent within common research methodologies and assessment modalities employed to measure the aforementioned strength and muscularity profiles (Kubo et al, 2010; Veale et al, 2010; Newton et al, 2006; Zakas, 2006).

While earlier investigations have endeavoured, with limited success, to match strength and muscularity profiles of athletes to their stage of development or level of profession, no studies have yet attempted to describe these profiles, or assess lower limb laterality within athletes of various technical competencies. As successful athletes are characteristically different to less successful athletes (Nevill et al, 2009; Rampini, Impellizzeri, Castagna, Coutts & Wisloff, 2009), and as kicking accuracy is critically important in football sports (Ball, 2007; Dichiera et al, 2006), it seems reasonable to investigate whether lower limb symmetry or lateral dominance enhances or influences technical proficiency of the kicking skill. It is therefore the purpose of this study to assess the unilateral and bilateral leg strength and leg mass characteristics of the kicking and support limbs within accurate and inaccurate kickers.

7.2. Methods

7.2.1. Participants

Thirty-one Australian footballers (age: 22.1 ± 2.8 yrs; mass: 85.1 ± 13.0 kg; height: 181.1 ± 7.0 cm; BMI: 25.9 ± 3.2) were recruited from the Western Australian Football League (WAFL) for participation within this study. All athletes had a minimum of five years total playing experience, with at least two consecutive years of experience at their current playing level. Athletes were void of injuries and contraindications at the time of testing; and were not permitted to perform any strenuous exercise or lower body resistance training within 48 hours of their assigned testing session. All athletes were notified of the potential risks involved, and provided written informed consent for participation. Ethics approval was provided by Edith Cowan University's Human Research Ethics Committee.

7.2.2. Study Design

This study utilised an acute, between groups, cross-sectional design consisting of a single two hour testing session. Testing sessions commenced with anthropometric measures including height, weight and limb length; followed by an assessment of whole-body composition and lower body segmental mass characteristics (lean, fat, total) of the thigh, shank and foot across both kicking and support limbs using dual energy x-ray absorptiometry (DEXA). Athletes were then taken through a general dynamic warm-up, prior to a series of lower limb isometric strength measures (unilateral and bilateral). Following this, a mechanically specific warm-up was provided (kicking over variable distances), in order to stabilise their kicking performance (Amiri-Khorasani, Osman & Yusof, 2010). The kicking protocol (drop punt over 20 metres) was then completed. Subjects were required to wear their club issued football shorts, and were provided with indoor football shoes (Nike5 Bomba, Nike Inc, USA) for use during the testing session. All athletes were thoroughly familiarised with all testing procedures prior to the commencement of testing. Following the assessment and analysis of their kicking performance, subjects were subsequently assigned to accurate (n = 15) and inaccurate (n = 16) groups for analysis (Table 1), in accordance with specific accuracy determination criteria.

Table 1. Subject characteristics for accurate and inaccurate groups.

Subject Characteristics	Accurate Kickers	Inaccurate Kickers
Age (yrs)	21.7 (± 3.3)	23.1 (± 1.9)
Height (cm)	181.7 (± 6.7)	180.8 (± 7.3)
Weight (kg)	80.6 (± 8.0)	89.4 (± 15.2) [a]
Body Mass Index (BMI)	24.4 (± 1.5)	27.3 (± 3.8) [a]
Total Body Fat (%)	11.1 (± 2.0)	17.4 (± 5.2) [a]
Kicking Leg Length (cm)	87.3 (± 3.3)	85.7 (± 3.6)
Kicking Accuracy (%)	91.3 (± 11.3)	57.5 (± 16.4) [a]

Note: Values are expressed as mean ± *SD.*
[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.

7.2.3. Anthropometrics

Standing height was recorded to the nearest 0.1 centimetre using a wall-mounted stadiometer, with body weight recorded to the nearest 0.1 kilogram using a standard electronic weighing scale. Limb length of the kicking leg was assessed using a non-retracting measuring tape, from the greater trochanter of the femur (proximal end), to the lateral malleolus of the fibula (distal end), and was recorded to the nearest 0.1 centimetre. Standing height and limb length measures were performed three times for each subject, with the average of the three trials retained for analysis.

7.2.4. Strength Assessment

Unilateral and bilateral lower body isometric strength assessments were performed on both lower limbs (kicking and support legs) using the isometric back squat exercise at preset hip and knee joint angles of 140°. These joint angles were assessed using a handheld goniometer, and were selected on the basis of positional specificity, to best correspond with maximal force production at zero velocity (Nuzzo, McBride, Cormie & McCaulley, 2008;

Haff et al, 2005; Haff et al, 1997). In particular, maximal strength (peak force [PF]) was identified using a uniaxial force plate (400 series Performance Plate; Fitness Technology, Adelaide, Australia) sampling at 600Hz; data acquisition software (Ballistic Measurement System [BMS]; Fitness Technology, Adelaide, Australia); a standard Olympic barbell (mass: 20kg; Eleiko, Sweden); and a heavy duty strap (SureTie, Zenith, NSW, Australia) designed to resist high loads (max: 4218N (430kg)), seen in Figure 1. Peak force reliability using this apparatus was assessed prior to the current study, revealing very high between-trial, reliability for bilateral (CV ≤ 3.6%; ICC ≥ 0.973) and unilateral (CV ≤ 4.7%; ICC ≥ 0.961) isometric conditions (Hart, Nimphius, Cochrane & Newton, 2012). For each bilateral trial, subjects adopted a traditional back squat position under the pre-set height of the bar, in order to elicit the previously determined hip and knee flexion angles of 140° (Figure 1a). For each unilateral trial, subjects were required to reposition the active leg under their centre of mass while removing their inactive leg from the force plate by flexing it at the knee (Figure 1b). Due to unilateral repositioning, hip and knee angles were re-assessed to ensure current bar-height settings met the 140° joint angle criteria.

Athletes were provided with considerable sub-maximal familiarisation (10 minutes duration interspersed with recovery) of all three trial types [Bilateral, BL; Unilateral (Kicking), KL; Unilateral (Support), SL], prior to performing a total of nine lower body maximal isometric contractions: three bilateral and six unilateral (kicking and support limb) trials. All subjects identified their right leg as the kicking limb and left leg as support limb. The order of testing was randomised and counterbalanced to negate the effects of muscular potentiation or fatigue (Hodgson, Docherty & Robbins, 2005; Rassier & MacIntosh, 2000). Subjects were required to maintain maximal contractions for a period of five seconds, and were provided with two minutes passive recovery between each maximal effort. The investigator, and two research assistants provided verbal encouragement, and visually monitored athlete technique during each trial to ensure postural and mechanical compensatory adjustments did not occur; and ensured athlete safety was maintained.

(A) **(B)**

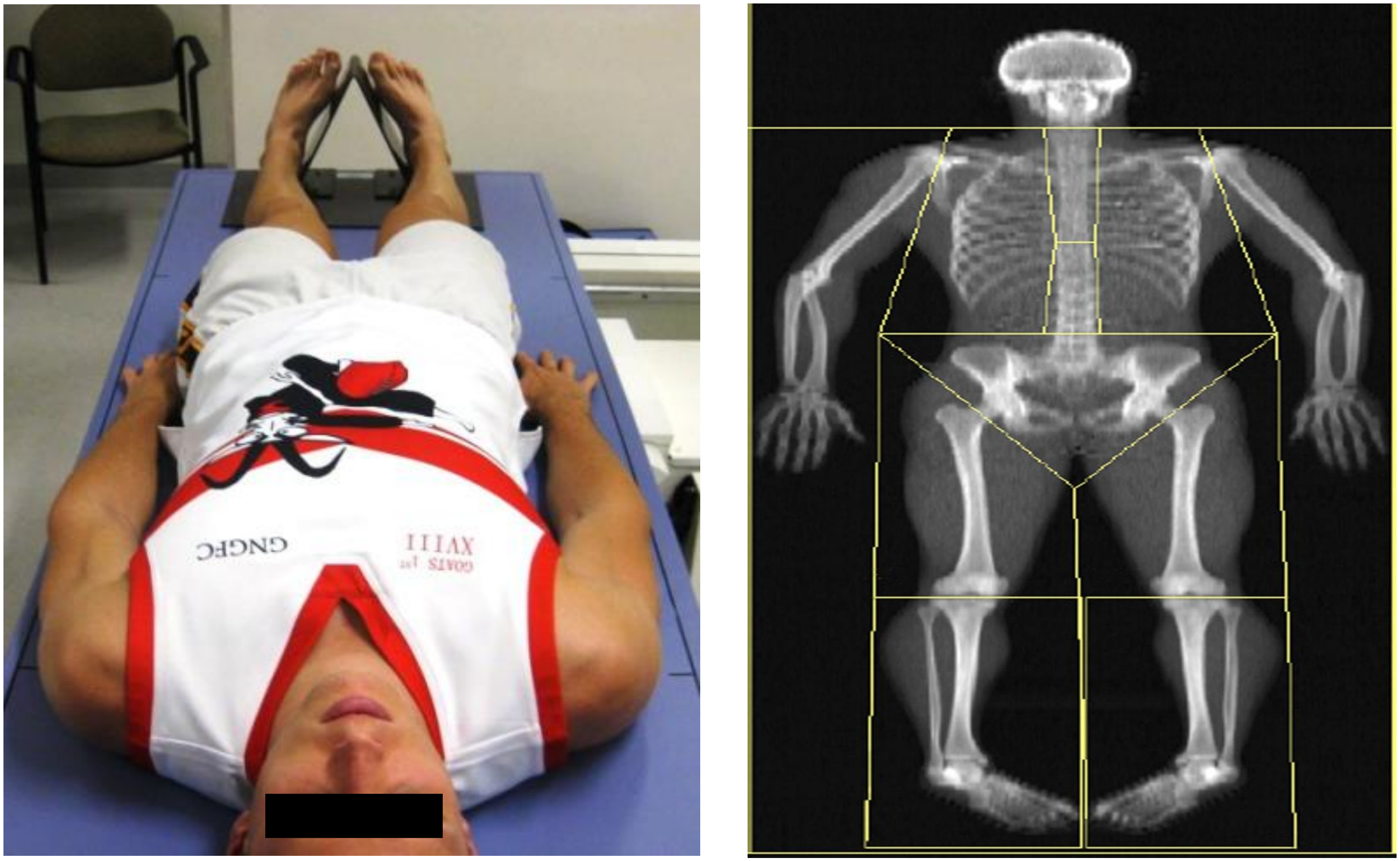
Figure 1. Isometric apparatus set-up and operation, with (a) correct hip and knee flexion angles of 140° during a bilateral trial, and (b) an illustration of correct limb positioning during a left leg unilateral isometric trial as used within this study.

7.2.5. Force-Time Analysis

The best trial for each isometric condition (BL, KL, SL) was chosen for analysis, identified by the greatest peak force output produced. The force-time data of these trials were exported for further analysis; with the maximum force output identified as peak force (PF). Absolute strength (bilateral and unilateral) was represented by peak force, with relative strength determined by dividing peak force (N) by body weight (N). Unilateral strength imbalance was assessed by comparing the unilateral peak force produced by each limb; and was calculated by dividing the peak force of the kicking limb by the peak force of the support limb. A unilateral imbalance score below 1.0 demonstrates a degree of lateral strength dominance to the support leg; whereas a score above 1.0 demonstrates a degree of lateral strength dominance to the kicking leg. In addition, bilateral deficit (BLD) outcomes were calculated by comparing the bilateral peak force value with the combined unilateral peak force values. Specifically, bilateral peak force was divided by the sum of unilateral (left and right limb) outputs, expressed formulaically as BL / [KL + SL]. A bilateral deficit was represented by a score below 1.0, with bilateral facilitation noted by a score above 1.0.

7.2.6. Scan Procedure

Lower body segmental mass and full-body composition components were assessed with dual energy x-ray absorptiometry (DEXA; Hologic Discovery A, Waltham, WA) using previously established, standardised and reliable body positioning procedures (Hologic, 2004; Peiffer et al, 2010). In particular, subjects assumed a stationary, supine position on the scanning bed with both arms pronated by their side, and hands facing the table. To ensure consistent body positioning, the DEXA operator manually assisted subjects in order to straighten their head, torso and pelvis; internally rotate and fixate their legs and feet at 45°; and ensured they were located within the DEXA scanning zone (Figure 2a). This has been shown to produce a scan/re-scan coefficient of variation below 1% in our laboratory (Peiffer et al, 2010).



(A) **(B)**

Figure 2. The DEXA scan and analysis process, with (A) a frontal view of the subject positioning process, illustrating pronated arms, and internally rotated thighs using a positioning device; and (B) the whole body, and segmental analysis zones used to define the lower body.

7.2.7. Scan Analysis

Whole body scans were analysed using the inbuilt analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, WA). The predefined, mandatory whole body model (Hologic, 2004) was applied to the scan image, separating the body into axial and appendicular sections to determine whole body composition and segmental composition of the kicking and support legs. Further analysis was performed to specifically identify and assess the segmental mass characteristics of the thigh and shank regions of the kicking and support legs using the sub-region analysis tool, in accordance with Dempster's body segment parameter boundaries for 2D studies (Winter, 1990). Due to the extension of the shank segment during the kicking motion in response to fixed plantarflexion of the foot (Orchard, Walt, McIntosh & Garlick, 1999), the shank segment was represented by the combination of both shank and foot regions in this study (Figure 2b).

Scan analysis reliability assessed prior to the current study revealed very high intra-tester reliability (CV ≤ 2.6%; ICC ≥ 0.941) and very high inter-tester reliability (CV ≤ 2.4%; ICC ≥ 0.961) for segmental sub-region analysis components. Segmental mass outputs were categorised into fat mass (g), lean mass (g) and total mass (g) values for each sub-region across all scans and subjects using Microsoft Excel (Microsoft, Redmond, WA). Relative lean mass for each segment and limb was calculated by dividing the amount segmental mass (g) by total body mass (g). The symmetry index (SI) for lean and total mass components was determined using a previously established calculation (Gouwanda & Senanayake, 2011; Sadeghi et al, 2000; Herzog, Nigg, Read & Olsson, 1989):

$$SI = \frac{(\text{Support Leg} - \text{Kicking Leg})}{0.5(\text{Support Leg} + \text{Kicking Leg})} \text{ x } 100\%$$

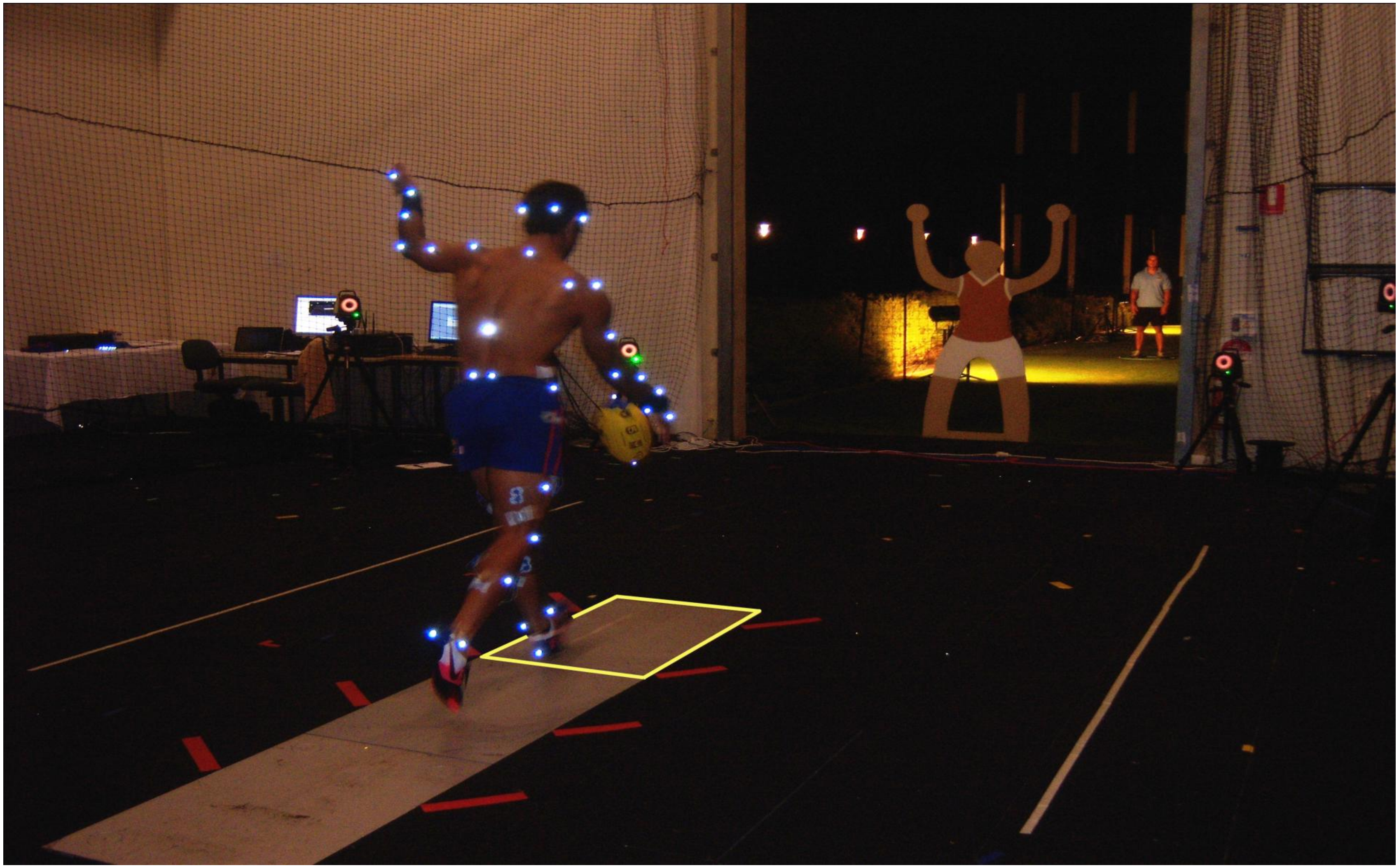


Figure 3. The kicking protocol set-up, with the athlete performing the drop punt, over an obstacle (height: 6 ft), to a stationary human target 20 metres from the kicking zone (outlined, dimensions: 1.0m x 0.7m).

7.2.8. Kicking Protocol

Kicking technique was assessed using the drop punt kick, performed with an Australian football (450g, Sherrin, Victoria, AU) inflated to official air pressure specifications (67 – 75 kPa) (Ball, 2008), using an electronic air pump (Air Erupt, Volcano, Taiwan). Athletes were required to produce ten drop punt kicks to a stationary human (player) target situated 20 metres from the centre of the kicking zone with the intention to deliver the ball as accurately as possible to the specified target (Figure 2). The twenty meter distance was chosen to correspond with other kicking accuracy literature in Australian Football (Young et al, 2010; Dichiera et al, 2006), and to replicate game-based accuracy demands when kicking to another player, as short kicks are often used to deliver a ball to another player in Australian Football (Dichiera et al, 2006). A life-sized obstacle representing an opposite player (base-to-head height: 6 ft; base-to-hand height: 7 ft) was positioned between the kicker and their target to control for minimum kicking trajectory, and to increase game-test specificity in the laboratory environment as Australian Footballers are regularly required to kick a ball to another player over an opponent defending space on the field.

Prior to commencing the kicking protocol, subjects completed a series of mechanically specific warm-up sets (5 drop punt kicks over 20m, 30m and 40m respectively, totalling 15 warm-up trials). Their ten official drop punt trials were then completed with a one minute recovery provided between each kick. For the trial to be considered successful, the athlete had to produce an approach consisting of at least two steps prior to planting their foot within the assigned kicking zone. Any trials which did not meet this criterion were considered invalid, and a repeat kicking trial subsequently provided until ten successful kicks were produced. Angle of approach was not standardised.

7.2.9. Accuracy Determination

Table 2. Accuracy grading and determination criteria for human target kicking outcomes.

Assigned Score	Description of Ball Delivery to Target
1 (Accurate)	The ball is delivered directly to the target, between the waist and head of the receiving player. The target should not reach or jump in any direction from their stationary position for this score to be awarded.
2 (Moderate)	The ball slightly deviates from the target, though not excessively (within the targets reach). The target may take one step or reach in any direction; jump directly upwards; or kneel down from their stationary position for this score to be awarded. No combined “step and reach” or “jump and reach” are allowed.
3 (Inaccurate)	The ball misses the target by any margin beyond the limits seen within the ‘Accurate’ or ‘Moderate’ grading criteria. If the target needs to step and reach; jump and reach; or take more than one step to receive the ball, or, if the ball misses the target zone all together; it is awarded an inaccurate score.

Kicking accuracy was assessed using a customised numerical scoring system. All kicks were visually graded immediately following each trial by the lead researcher; the human target (receiving the ball) and a research assistant. All assigned scores were recorded and visually confirmed using a two-dimensional digital video camera (MV710I PAL, Canon, NSW, AU). The scoring system for each kick spanned from 1 (accurate), 2 (moderate) and 3 (inaccurate), and was judged by the location of ball delivery to the target (Table 2). Following ten successful kicks, each athlete’s scores were summated, with total scores ranging between 10 to 30 points. Athletes were classified as either accurate (10 – 18 points) or inaccurate (19 – 30 points), resulting in fifteen accurate kickers, and sixteen inaccurate kickers. Kicking accuracy was subsequently determined by calculating the percentage of accurate trials produced within the ten trial quota. Athlete performance and accuracy grading reliability assessed prior to the current study revealed very high intra-tester reliability (CV ≤ 1.6%; ICC ≥ 0.997), very high inter-tester reliability (CV ≤ 3.3%; ICC ≥ 0.986) and very high between-day reliability of kicking performance (CV ≤ 4.2%; ICC ≥ 0.975).

7.2.10. Statistical Analysis

An independent t-test was used for all dependant variables to determine whether significant differences were evident between the subject characteristics, leg mass characteristics and leg strength characteristics of accurate and inaccurate kickers. Statistical significance was set at an alpha level of $p \leq 0.05$ (with a 95% confidence level). Correlational analysis was performed using Pearson's product moment (PPM) correlation coefficient (r) to determine the strength of relationship between leg mass and leg strength variables to ranking of kicking accuracy. The strength of relationship was classified in accordance with Hopkins (2002): $r \pm 0.3$ is moderate; $r \pm 0.5$ is strong; $r \pm 0.7$ is very strong; $r \pm 0.9$ is nearly perfect; and $r \pm 1.0$ is perfect. All statistical computations were performed using a statistical analysis program (SPSS, Version 17.0; Chicago, IL).

7.3. Results

7.3.1. Limb Strength

Leg strength characteristics are presented in Table 3. While no significant differences were noted between bilateral or unilateral strength characteristics in either absolute or relative expressions; moderate positive correlations were evident between kicking accuracy, relative bilateral strength ($r \approx 0.401$) and relative unilateral support-leg strength ($r \approx 0.379$).

Furthermore, unilateral strength imbalance was a noteworthy factor between accurate and inaccurate groups, with inaccurate kickers demonstrating significantly less strength in their support leg than their accurate counterparts (p = 0.002). This interaction was additionally supported by a large negative correlation (*r* = -0.516) with kicking accuracy.

Table 3. Strength characteristics for accurate and inaccurate groups with correlations to kicking accuracy scores.

	Accurate	Inaccurate	% Diff	ES	PPM (*r*)
Absolute Strength					
[BL] – Bilateral (N)	2473 (± 475)	2352 (± 770)	4.89	0.19	0.233
[SL] – Left Unilateral (N)	1914 (± 426)	1769 (± 531)	7.57	0.30 [e]	0.291
[KL] – Right Unilateral (N)	1871 (± 389)	1887 (± 545)	0.84	0.03	0.122
Relative Strength					
[BL] – Bilateral (N/N)	3.13 (± 0.5)	2.76 (± 0.9)	11.82 [d]	0.51 [e]	0.401 [c]
[SL] – Left Unilateral (N/N)	2.44 (± 0.5)	2.09 (± 0.7)	14.34 [d]	0.58 [e]	0.379 [c]
[KL] – Right Unilateral (N/N)	2.38 (± 0.5)	2.21 (± 0.6)	7.14	0.31 [e]	0.248
Other Characteristics					
Unilateral Imbalance (KL/SL)	0.99 (± 0.1)	1.08 (± 0.1) [a]	8.33	0.90 [f]	-0.516 [b]
Bilateral Deficit ([KL+SL]/BL)	0.67 (± 0.1)	0.64 (± 0.1)	4.48	0.30 [e]	0.103

Note: Values are expressed as mean ± *SD*, SL = Support Leg, KL = Kicking Leg, ES = Effect Size.
[a] Statistical significance ($\alpha \leq 0.01$) between accurate and inaccurate kickers.
[b] Strong relationship ($r \geq 0.5$) with kicking accuracy.
[c] Moderate relationship - ($r \geq 0.3$) with kicking accuracy.
[d] Percent difference ≥ 10% between Accurate and Inaccurate kickers.
[e] Small effect size (ES ≥ 0.2) evident between groups (Hopkins, 2000; Hopkins, 2002).
[f] Moderate effect size (ES ≥ 0.6) evident between groups (Hopkins, 2000; Hopkins, 2002).

7.3.2. Limb Mass

Leg mass characteristics are provided in Table 4. Significant differences were evident within thigh, shank and whole leg segments of both kicking and support limbs. In particular, lean mass was significantly higher (p = 0.000 to 0.004), and fat mass was significantly lower (p = 0.000 to 0.024) in accurate kickers across all segments of both kicking and support limbs, with higher total relative leg mass (p = 0.048) in the support leg of accurate kickers. This interaction was further evidenced through correlational analysis (Table 5). Lean mass was positively associated with kicking accuracy, demonstrating moderate-to-very strong correlations (Kicking: r = 0.462 to 0.631; Support: r = 0.492 to 0.698), while fat mass was negatively associated with kicking accuracy, demonstrating moderate-to-strong correlations (Kicking: r = -0.431 to -0.580; Support: r = -0.534 to -0.585). The total mass of the support leg was also positively correlated with kicking accuracy (r = 0.433).

7.3.3. Limb Symmetry

The symmetry index for lean and total mass components of the thigh, shank and whole limb segments for accurate and inaccurate kickers are provided in Table 6. Accurate kickers demonstrated significantly smaller asymmetry than inaccurate kickers, with the most notable differences visible in lean mass across all segments (Figure 4; p = 0.003 to 0.029), and total mass in the thigh (p = 0.003) and whole limb (p = 0.0021). The negative symmetry indices for the inaccurate kickers illustrates the lower mass quantities prevalent in their support limb (relative to their kicking limb), which corresponds with the weaker support leg noted by their unilateral strength imbalance. Moderate positive correlations (r = 0.312 to 0.406) were also observed between kicking accuracy and symmetry index scores, highlighting a potential relationship between reduced asymmetry and enhanced kicking performance.

Table 4. Relative leg mass characteristics of the kicking and support limbs for accurate and inaccurate kickers.

	Accurate [Kicking]	Inaccurate [Kicking]	Accurate [Support]	Inaccurate [Support]
Thigh Segment				
- Lean (%)	10.14 (± 0.6)	9.36 (± 0.8) [a]	10.06 (± 0.5)	9.03 (± 0.8) [a]
- Fat (%)	1.46 (± 0.4)	2.44 (± 0.8) [a]	1.44 (± 0.4)	2.37 (± 0.7) [a]
- Total (%)	11.93 (± 0.4)	12.14 (± 0.7)	11.89 (± 0.5)	11.75 (± 0.7)
Shank Segment				
- Lean (%)	4.65 (± 0.3)	4.08 (± 0.5) [a]	4.70 (± 0.3)	4.01 (± 0.5) [a]
- Fat (%)	0.71 (± 0.2)	0.90 (± 0.2) [a]	0.58 (± 0.1)	0.96 (± 0.3) [a]
- Total (%)	5.78 (± 0.3)	5.37 (± 0.4) [a]	5.71 (± 0.2)	5.37 (± 0.4) [a]
Whole Leg				
- Lean (%)	14.79 (± 0.7)	13.44 (± 1.1) [a]	14.77 (± 0.6)	13.05 (± 1.1) [a]
- Fat (%)	2.16 (± 0.5)	3.35 (± 1.0) [a]	2.03 (± 0.5)	3.33 (± 1.0) [a]
- Total (%)	17.71 (± 0.5)	17.51 (± 0.8)	17.60 (± 0.5)	17.11 (± 0.8) [a]

Note: Values are expressed as mean (± *SD)*, relative to total body mass.

[a] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.

Table 5. Pearsons Product Moment, Correlation Coefficients for Leg Mass to Kicking Accuracy outcomes.

	Kicking Thigh	Kicking Shank	Kicking Leg	Support Thigh	Support Shank	Support Leg
- Lean (%)	$r = 0.631$ [b]	$r = 0.462$ [c]	$r = 0.631$ [b]	$r = 0.694$ [b]	$r = 0.492$ [b]	$r = 0.702$ [a]
- Fat (%)	$r = -0.580$ [b]	$r = -0.431$ [c]	$r = -0.569$ [b]	$r = -0.585$ [b]	$r = -0.534$ [b]	$r = -0.582$ [b]
- Total (%)	$r = 0.085$	$r = 0.344$ [c]	$r = 0.279$	$r = 0.305$ [c]	$r = 0.285$	$r = 0.433$ [c]

[a] Very strong effect - ($r \geq 0.7$).
[b] Strong effect - ($r \geq 0.5$).
[c] Moderate effect - ($r \geq 0.3$).

Table 6. Symmetry Index (imbalance) between kicking and support legs of accurate and inaccurate kickers.

Leg Segments	Accurate Kickers	Inaccurate Kickers	Significance	PPM (r)
Thigh (Lean**)**	-0.76 (± 3.9)	-3.60 (± 2.8)	$p = 0.029$ [b]	$r = 0.323$ [c]
Thigh (Total**)**	-0.36 (± 2.8)	-3.31 (± 2.1)	$p = 0.003$ [a]	$r = 0.406$ [c]
Shank (Lean**)**	1.19 (± 2.5)	-1.49 (± 2.9)	$p = 0.012$ [b]	$r = 0.312$ [c]
Shank (Total**)**	-1.17 (± 2.0)	-0.17 (± 2.8)	$p = 0.266$	$r = -0.123$
Whole Leg (Lean**)**	-0.13 (± 2.1)	-2.90 (± 2.5)	$p = 0.003$ [a]	$r = 0.402$ [c]
Whole Leg (Total**)**	-0.60 (± 1.9)	-2.32 (± 1.9)	$p = 0.021$ [b]	$r = 0.341$ [c]

Note: Values are expressed as mean (± *SD)* of calculated symmetry index (SI).
[a] Statistical significance ($\alpha \leq 0.01$) between accurate and inaccurate kickers.
[b] Statistical significance ($\alpha \leq 0.05$) between accurate and inaccurate kickers.
[c] Moderate relationship - ($r \geq 0.3$) with kicking accuracy.

7.3.3. Limb Symmetry

The symmetry index for lean and total mass components of the thigh, shank and whole limb segments for accurate and inaccurate kickers are provided in Table 6. Accurate kickers demonstrated significantly smaller asymmetry than inaccurate kickers, with the most notable differences visible in lean mass across all segments (Figure 4; p = 0.003 to 0.029), and total mass in the thigh (p = 0.003) and whole limb (p = 0.0021). The negative symmetry indices for the inaccurate kickers illustrates the lower mass quantities prevalent in their support limb (relative to their kicking limb), which corresponds with the weaker support leg noted by their unilateral strength imbalance. Moderate positive correlations (*r* = 0.312 to 0.406) were also observed between kicking accuracy and symmetry index scores, highlighting a potential relationship between reduced asymmetry and enhanced kicking performance.

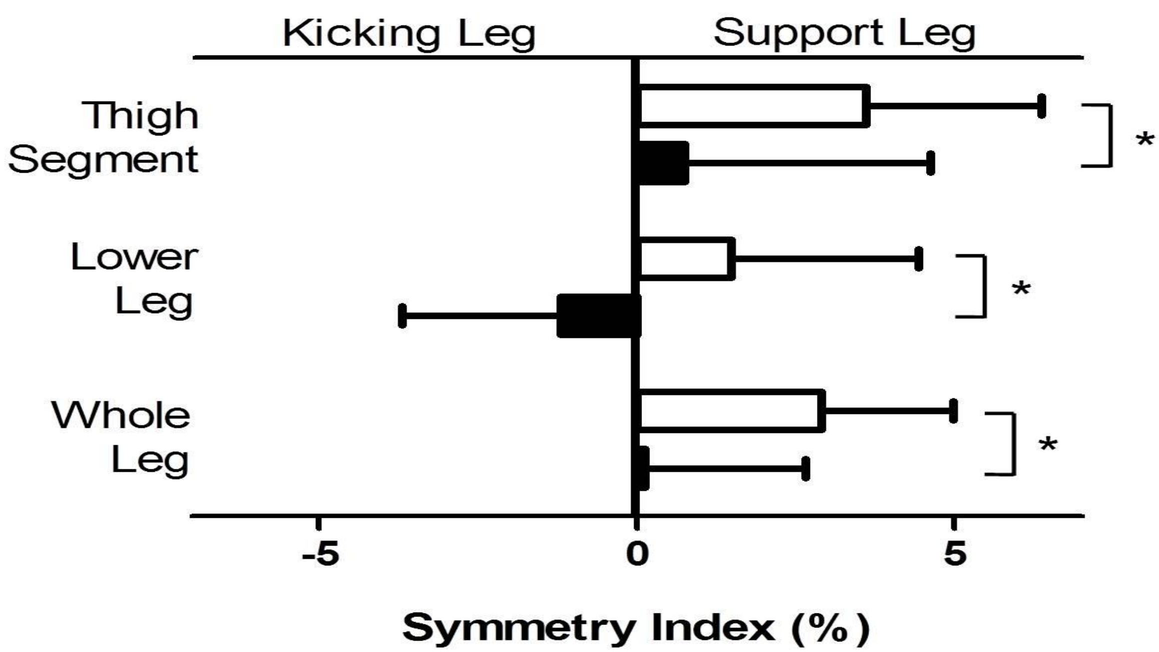


Figure 4. Lean mass imbalance (symmetry index) of the thigh segment, shank segment and whole leg, showing deficiency (lower mass quantities) in the kicking leg (left) and support leg (right).

7.4. Discussion

Despite the tactical advantage provided by the ability to kick competently with both limbs (Ball, 2011; Haaland & Hoff, 2003), footballers tend to develop and selectively use a preferred limb for kicking, and a preferred limb for balance and support (Ball, 2011; Kubo et al, 2010; Gstottner et al, 2009; Iga et al, 2009; Wong et al, 2007; Zakas, 2006). Given that repetitious asymmetrical activities generate asymmetrical hypertrophic responses in muscle (Hides et al, 2010; Stewart et al, 2010; Baczkowski et al, 2006), it would be logical to expect a laterality effect to exist between the kicking and support limbs in response to the frequency of differential stresses imposed on the lower body by the kicking action in football sports. Unfortunately, previous research has been unable to distinguish whether a laterality effect positively exists in football sports (Hides et al, 2010; Kubo et al, 2010; Hoshikawa et al, 2009; Kearns et al, 2001); and whether it suitably influences performance, or increases injury incidence and severity (Askling, Karlsson & Thorestensson, 2003; Bennell et al, 1998; Brocket, Morgan & Proske, 2004; Newton et al, 2006; Orchard et al, 1997). To address this notable disparity within the literature, the purpose of the current study was to investigate whether lower limb symmetry influenced drop punt kicking performance within football sports.

The primary findings of this study demonstrated a positive interaction between lower limb symmetry and kicking performance, providing support for the modification and manipulation of lower limb strength and muscularity in favour of greater limb symmetry within football players. Footballers who were identified as accurate kickers produced characteristically different lower limb strength and segmental mass profiles than their inaccurate counterparts. In particular, accurate kickers did not have any visible strength imbalances or mass asymmetries across the kicking and support limbs, and contained greater relative lean mass quantities in all segments across both limbs; whereas inaccurate kickers contained notable asymmetries in lower limb muscularity and unilateral strength, particularly favouring their preferred kicking leg. As no significant differences were evident between the strength of the kicking leg in each group, the visible imbalance within inaccurate kickers might demonstrate a potential deficiency in their support leg, which could considerably influence the proficient production of the kicking skill.

In particular, footballers must adopt unipedal postures when kicking (Paillard et al, 2006); relying on a stable platform to rapidly and accurately swing the kicking leg beneath the body to strike the ball (Young & Rath, 2011; Dichiera et al, 2006). As the support leg plays an important role in the generation and maintenance of athletic stability during a kicking task (Dichiera et al, 2006), any physical weakness may compromise the quality of the kicking outcome produced. Specifically, lean mass of the support leg importantly stabilises the hip and knee joints during active loading, adequately supporting total body weight, while also resisting the torque developed by the kicking leg (Rahmana et al, 2005), subsequently allowing more skilful athletes to maintain balance as they powerfully kick the ball (Kubo et al, 2010; Gstottner et al, 2009; Matsuda, Demura & Uchiyama, 2008; Gerbino, Griffin & Zurakowski, 2007; Wong et al, 2007). Given the high level of physical conditioning required by footballers to routinely perform the kicking skill (Manolopoulos, Papadopoulos & Kellis, 2006; Bangsbo, 1994); the notable asymmetry and inferiority of relative lean mass illustrated within the support leg of inaccurate kickers within this study might potentially explain their low levels of kicking accuracy and diminished overall performance.

In addition, the reduced magnitude of lean mass within the support leg of inaccurate kickers provides a plausible explanation for the somewhat proportionate loss of unilateral strength in the support limb, leading to the evident strength imbalance between limbs. As force generation is directly related to muscle size (Hoshikawa et al, 2009; Jones, Bishop, Woods & Green, 2008; Perez-Gomez et al, 2008a; Perez-Gomez et al, 2008b; Andersen & Aagaard, 2006), a reduced strength capacity in the support leg may functionally limit the effective stabilisation and control of the kicking skill within inaccurate kickers. Furthermore, accurate kickers contained significantly greater quantities of relative lean mass in all segments across both limbs. Given the moderate correlations of relative strength, and strong-to-very strong correlations of relative lean mass to the production of kicking accuracy, it could be theorised that higher muscle mass and strength levels will recruit a lower percentage of the maximum capacity of the system in order to acquire a given kicking distance. This should enable greater co-ordination and control within the kicking action as a lower proportion of the motor unit pool is used by each muscle to achieve the desired performance outcome. This study therefore adds further support for the notion that strength and muscularity levels are capable of differentiating successful players from their less successful counterparts (Hoshikawa et al, 2009; Iga et al, 2009; Gissis et al, 2006; Hansen, Bangsbo, Twisk, Klausen & 1999; Tumilty, 1993), whilst also playing a critical role in kicking performance (Young & Rath, 2011; Manolopoulos et al, 2006; Bangsbo, 1994).

Although a clear difference in strength was observed between the support leg of accurate and inaccurate kickers in this study; the non-significant difference in the kicking leg may be a consequence of the strength assessment used (Young & Rath, 2011). Isometric strength protocols are able to represent dynamic force capabilities if the premise of positional specificity is honoured (Hart et al, 2012; Gamble, 2006; Haff et al, 1997). In this regard, the support leg was appropriately assessed as the hip and knee angles used during strength testing were similar to those experienced during the support phase of the drop punt (Dichiera et al, 2006). However, kicking leg muscle function is bi-articular; generating rapid, high-speed, multi-joint and multi-segmental actions which have been difficult to assess in the literature due to highly specific movement patterns (Young & Rath, 2011; Kellis & Katis, 2007b; Masuda et al, 2005), which was also a limitation of the current study. Therefore, to resolve the issue of mechanical specificity, future studies examining muscle function and strength characteristics of footballers are encouraged to develop separate strength assessments for the kicking and support limbs based on their corresponding action during the kicking motion.

In conclusion, this paper demonstrates the importance of developing greater symmetry in leg strength and muscularity between the kicking and support limbs; in addition to generating greater levels of relative muscular strength within football players as a tool to potentially enhance the technical proficiency of the kicking skill in favour of greater accuracy. As differential stresses are routinely imposed upon the lower limbs during the performance of many technical skills inherent within football sports, it would seem appropriate to utilise strength and conditioning interventions, in addition to game-based loading, as a mechanism to maintain or increase limb symmetry, in an effort to optimise performance while minimising injury incidence and severity. However, it is worthwhile to note that while lower limb symmetry does appear desirable, it does not necessarily create accuracy; rather, the prevalence of symmetry may provide an athlete with the optimal foundation and opportunity to produce technically proficient performances. Further research needs to be conducted in order to assess the broader influence of lower limb symmetry, or lateral dominance across a wide range of sport-specific skills found within football sports, and to assess whether there are positive or negative influences on subsequent injury risk and severity.

7.5. References

Amiri-Khorasani, M., Osman, A., & Yusof, A. (2010). Kinematic analysis: Number of trials necessary to achieve performance stability during soccer instep kicking. *Journal of Human Kinetics, 23,* 15-20.

Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology, 96*(1), 46-52.

Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine and Science in Sports*, *13*(4), 244-250.

Baczkowski, K., Marks, P., Silberstein, M., & Schneider-Kolsky, M. E. (2006). A new look into kicking a football: an investigation of muscle activity using MRI. *Australasian Radiology, 50*(4), 324-329.

Ball, K. (2007). Foot-ball interaction in Australian Rules football. *Journal of Sports Science and Medicine, 6*(Suppl. 10), 46.

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics*, *7*(1), 10-23.

Ball, K. (2011). Kinematic comparison of the preferred and non-preferred foot punt kick. *Journal of Sports Sciences, 29*(14), 1545-1552.

Bangsbo, J. (1994). The physiology of soccer--with special reference to intense intermittent exercise. *Acta Physiologica Scandinavia*, *619*, 1-155.

Bennell, K., Wajswelner, H., Lew, P., Schall-Riaucour, A., Leslie, S., Plant, D., et al. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *British Journal of Sports Medicine, 32*(4), 309-314.

Brockett, C. L., Morgan, D. L., & Proske, U. (2004). Predicting hamstring strain injury in elite athletes. *Medicine and Science in Sports and Exercise, 36*(3), 379-387.

Cameron, M., & Adams, R. (2003). Kicking footedness and movement discrimination by elite Australian Rules footballers. *Journal of Science and Medicine in Sport, 6*(3), 266-274.

Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J. C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *International Journal of Sports Medicine, 22*(1), 45-51.

Croisier, J. L., Forthomme, B., Namurois, M. H., Vanderthommen, M., & Crielaard, J. M. (2002). Hamstring muscle strain recurrence and strength performance disorders. *American Journal of Sports Medicine, 30*(2), 199-203.

Dichiera, A., Webster, K. E., Kuilboer, L., Morris, M. E., Bach, T. M., & Feller, J. A. (2006). Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. *Journal of Science and Medicine in Sport, 9*(4), 292-298.

Gamble, P. (2006). Implications and Applications of Training Specificity for Coaches and Athletes. *Journal of Strength and Conditioning, 28*(3), 54-58.

Gerbino, P. G., Griffin, E. D., & Zurakowski, D. (2007). Comparison of standing balance between female collegiate dancers and soccer players. *Gait and Posture, 26*(4), 501-507.

Gissis, I., Papadopoulos, C., Kalapotharakos, V. I., Sotiropoulos, A., Komsis, G., & Manolopoulos, E. (2006). Strength and speed characteristics of elite, subelite, and recreational young soccer players. *Research in Sports Medicine, 14*(3), 205-214.

Gouwanda, D., & Senanayake, S. M. (2011). Identifying gait asymmetry using gyroscopes--a cross-correlation and Normalized Symmetry Index approach. *Journal of Biomechanics, 44*(5), 972-978.

Gstottner, M., Neher, A., Scholtz, A., Millonig, M., Lembert, S., & Raschner, C. (2009). Balance ability and muscle response of the preferred and nonpreferred leg in soccer players. *Motor Control, 13*(2), 218-231.

Haaland, E., & Hoff, J. (2003). Non-dominant leg training improves the bilateral motor performance of soccer players. *Scandinavian Journal of Medicine and Science in Sports, 13*(3), 179-184.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., et al. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *Journal of Strength and Conditioning Research, 19*(4), 741-748.

Haff, G. G., Stone, M. H., O'Bryant, H., Harman, E., Dinan, C., Johnson, R., et al. (1997). Force-time dependent characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research, 11*, 269-272.

Hansen, L., Bangsbo, J., Twisk, J., & Klausen, K. (1999). Development of muscle strength in relation to training level and testosterone in young male soccer players. *Journal of Applied Physiology, 87*(3), 1141-1147.

Hart, N. H., Nimphius, S., Cochrane, J. L., & Newton, R. U. (2012). Reliability and validity of unilateral and bilateral isometric strength using a customised, portable apparatus. *Journal of Australian Strength and Conditioning, 20*, 61-67.

Herzog, W., Nigg, B. M., Read, L. J., & Olsson, E. (1989). Asymmetries in ground reaction force patterns in normal human gait. *Medicine and Science in Sports and Exercise, 21*(1), 110-114.

Hides, J., Fan, T., Stanton, W., Stanton, P., McMahon, K., & Wilson, S. (2010). Psoas and quadratus lumborum muscle asymmetry among elite Australian Football League players. *British Journal of Sports Medicine, 44*(8), 563-567.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-Activation Potentiation: Underlying physiology and implications for motor performance. *Sports Medicine, 35*(7), 585-595.

Hologic. (2004). QDR for Windows XP Reference Manual: Hologic Inc.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Hoshikawa, Y., Iida, T., Muramatsu, M., Nakajima, Y., Fukunaga, T., & Kanehisa, H. (2009). Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *Journal of Sports Sciences, 27*(2), 129-138.

Iga, J., George, K., Lees, A., & Reilly, T. (2009). Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals. *Scandinavian Journal of Medicine and Science in Sports, 19*(5), 714-719.

Jones, E. J., Bishop, P. A., Woods, A. K., & Green, J. M. (2008). Cross-sectional area and muscular strength: a brief review. *Sports Medicine, 38*(12), 987-994.

Kearns, C. F., Isokawa, M., & Abe, T. (2001). Architectural characteristics of dominant leg muscles in junior soccer players. *European Journal of Applied Physiology, 85*(3-4), 240-243.

Kellis, E., & Katis, A. (2007b). The relationship between isokinetic knee extension and flexion strength with soccer kick kinematics: an electromyographic evaluation. *Journal of Sports Medicine and Physical Fitness, 47*(4), 385-395.

Kubo, T., Muramatsu, M., Hoshikawa, Y., & Kanehisa, H. (2010). Profiles of trunk and thigh muscularity in youth and professional soccer players. *Journal of Strength and Conditioning Research, 24*(6), 1472-1479.

Manolopoulos, E., Papadopoulos, C., & Kellis, E. (2006). Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scandinavian Journal of Medicine and Science in Sport, 16*(2), 102-110.

Masuda, K., Kikuhara, N., Demura, S., Katsuta, S., & Yamanaka, K. (2005). Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. *Journal of Sports Medicine and Physical Fitness, 45*(1), 44-52.

Masuda, K., Kikuhara, N., Takahashi, H., & Yamanaka, K. (2003). The relationship between muscle cross-sectional area and strength in various isokinetic movements among soccer players. *Journal of Sports Sciences, 21*(10), 851-858.

Matsuda, S., Demura, S., & Uchiyama, M. (2008). Centre of pressure sway characteristics during static one-legged stance of athletes from different sports. *Journal of Sports Sciences, 26*(7), 775-779.

McLean, B. D., & Tumilty, D. M. (1993). Left-right asymmetry in two types of soccer kick. *British Journal of Sports Medicine, 27*(4), 260-262.

Nevill, A., Holder, R., & Watts, A. (2009). The changing shape of "successful" professional footballers. *Journal of Sports Sciences*, *27*(5), 419-426.

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., et al. (2006). Determination of functional strength imbalance of the lower extremities. *Journal of Strength and Conditioning Research, 20*(4), 971-977.

Nunome, H., Ikegami, Y., Kozakai, R., Apriantono, T., & Sano, S. (2006). Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *Journal of Sports Sciences, 24*(5), 529-541.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707.

Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *American Journal of Sports Medicine, 25*(1), 81-85.

Orchard, J., Walt, S., McIntosh, A., & Garlick, D. (1999). Muscle activity during the drop punt kick. *Journal of Sports Sciences, 17*(10), 837-838.

Paillard, T., Noe, F., Riviere, T., Marion, V., Montoya, R., & Dupui, P. (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic Training, 41*(2), 172-176.

Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., et al. (2010). Strength and functional characteristics of men and women 65 years and older. *Rejuvenation Research, 13*(1), 75-82.

Perez-Gomez, J., Olmedillas, H., Delgado-Guerra, S., Ara, I., Vicente-Rodriguez, G., Ortiz, R. A., et al. (2008a). Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football. *Applied Physiology, Nutrition and Metabolism, 33*(3), 501-510.

Perez-Gomez, J., Rodriguez, G. V., Ara, I., Olmedillas, H., Chavarren, J., Gonzalez-Henriquez, J. J., et al. (2008b). Role of muscle mass on sprint performance: gender differences? *European Journal of Applied Physiology, 102*(6), 685-694.

Rahnama, N., Lees, A., & Bambaecichi, E. (2005). Comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics, 48*(11-14), 1568-1575.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.

Rassier, D., & MacIntosh, B. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*, 499-508.

Sadeghi, H., Allard, P., Prince, F., & Labelle, H. (2000). Symmetry and limb dominance in able-bodied gait: a review. *Gait and Posture, 12*(1), 34-45.

Saliba, L., & Hrysomallis, C. (2001). Isokinetic strength related to jumping but not kicking performance of Australian footballers. *Journal of Science and Medicine in Sport, 4*(3), 336-347.

Stewart, S., Stanton, W., Wilson, S., & Hides, J. (2010). Consistency in size and asymmetry of the psoas major muscle among elite footballers. *British Journal of Sports Medicine, 44*(16), 1173-1177.

Theoharopoulos, A., Tsitskaris, G., Nikopoulou, M., & Tsaklis, P. (2000). Knee strength of professional basketball players. *Journal of Strength and Conditioning Research, 14*(4), 457-463.

Thorborg, K., Couppe, C., Petersen, J., Magnusson, S. P., & Holmich, P. (2011). Eccentric hip adduction and abduction strength in elite soccer players and matched controls: a cross-sectional study. *British Journal of Sports Medicine, 45*(1), 10-13.

Tumilty, D. (1993). Physiological characteristics of elite soccer players. *Sports Medicine, 16*(2), 80-96.

Veale, J. P., Pearce, A. J., Buttifant, D., & Carlson, J. S. (2010). Anthropometric profiling of elite junior and senior Australian football players. *International Journal of Sports Physiology and Performance, 5*(4), 509-520.

Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement* (2nd ed.). Toronto: John Wiley & Sons, Inc.

Wong, P. L., Chamari, K., Chaouachi, A., Mao de, W., Wisloff, U., & Hong, Y. (2007). Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. *British Journal of Sports Medicine, 41*(2), 84-92.

Young, W. B., Newton, R. U., Doyle, T. L., Chapman, D., Cormack, S., Stewart, G., et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules Football: a case study. *Journal of Science and Medicine in Sport, 8*(3), 333-345.

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118.

Young, W. B., & Rath, D. A. (2011). Enhancing Foot Velocity in Football Kicking: The Role of Strength Training. *Journal of Strength and Conditioning Research, 25*(2), 561-566.

Zakas, A. (2006). Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. *Journal of Sports Medicine and Physical Fitness, 46*(1), 28-3.

8.0 – CHAPTER EIGHT – SUMMARY / CONCLUSIONS

The purpose of this thesis was to examine the kinanthropometric characteristics of accurate and inaccurate kickers in Australian Football in order to identify the potential influences or determinants of kicking accuracy when performing the drop punt kick. In particular, this series of research studies assessed the characteristics of Australian Footballers which are modifiable or influenced by athletic conditioning practices, including whole body composition; anthropometrics; segmental masses of the lower limbs; unilateral and bilateral leg strength; and lower limb kinematics produced during the kicking action. Five investigations were undertaken to establish valid and reliable measurement protocols, and subsequently quantify the necessary athletic characteristics required by this research.

The first study sought to establish a standardised in-vivo method to reliably quantify the segmental masses of the appendicular skeleton using DEXA technology. While whole body models have been routinely applied to separate the body into axial and appendicular sections, there was a need to create an appendicular model to further identify and examine the upper and lower extremities. This study established a reliable body positioning and scan analysis model to accurately identify the upper arm, forearm, hand, thigh, shank and foot segments, producing very high intra-tester reliability (CV $\leq$ 2.6%; ICC $\geq$ 0.941) and very high inter-tester reliability (CV $\leq$ 2.4%; ICC $\geq$ 0.961). The findings of this study provide a novel method to determine intralimb and interlimb segmental quantities of lean, fat and total mass, which could be used by strength and conditioning practitioners to monitor the efficacy of training interventions or identify potential deficiencies acquired through injury during the competitive season.

The second study aimed to determine whether a portable isometric strength device was able to derive valid and reliable representations of maximal lower limb strength and rate of force development characteristics under unilateral and bilateral conditions. Given that the portable isometric strength device contained no bar supports, and was unable to prevent horizontal sway; a less stable environment may compromise the ability to produce maximal isometric efforts. The results of this study were able to successfully demonstrate valid and reliable representations of maximal isometric force (peak force) under bilateral and unilateral conditions (CV $\leq$ 4.7%; ICC $\geq$ 0.961) when using the portable apparatus. Unfortunately, the portable device was unable to reliably determine the rate of force development across either bilateral or unilateral conditions (CV: 14.5% to 45.5%; ICC: 0.360 to 0.943), likely due to the increased stabilisation needed during the maximal efforts. The portable device may therefore provide a more sport-specific assessment of maximal strength in sports where balance is an important component in the target performance; such as the function of the support leg during the kicking motion.

Using the methodological approach established in study one; the third study sought to provide a detailed profile of the lower limb segmental mass characterstics of accurate and inaccurate kickers in Australian Football to determine whether these sub-groups of athletes exhibited different physical characteristics. Specifically, this study illustrated a noticeable difference in leg mass characteristics between accurate and inaccurate kickers. Accurate kickers contained significantly greater quantities of relative lean mass ($p \leq 0.004$; $r = 0.462$ to 0.698); significantly lower quantities of relative fat mass ($p \leq 0.024$; $r = -0.431$ to -0.585); and significantly higher lean-to-fat mass ratios ($p \leq 0.009$; $r = 0.482$ to 0.622) across all segments of the kicking and support limbs. In particular, this study demonstrated the importance of relative quantities of body mass components to performance outcomes; with the contractile properties of lean mass (skeletal muscle) contributing positively to skilful movements, and the inert properties of fat mass impacting negatively to sporting performances requiring the projection of a body through space; both of which appear to be deterministic characteristics for the kicking skill, and may subsequently adjust the temporal and technical strategy of Australian Footballers when performing the drop punt.

To examine how these lower limb characteristics may adjust the biomechanical strategy of Australian Footballers when kicking for accuracy; the fourth study aimed to assess whether greater overall leg mass could potentially optimise kicking performance in favour of greater accuracy, by enabling a proportionately lower angular velocity to be produced in order to achieve a given distance. Using the methodological approach established in study one to determine leg mass characteristics, in conjunction with three-dimensional kinematic data obtained from an optoelectronic device, this study did not find a relationship between foot velocity and kicking accuracy (r = -0.035 to -0.083). In fact, ball velocity was unable to be explained by either foot velocity or leg mass in isolation; rather, it was the co-contribution of these characteristics which were the discriminatory factors between accurate and inaccurate kickers. Furthermore, a significant and strong correlation between relative lean mass and kicking accuracy ($p \leq 0.001$; $r = 0.631$) was evident. As temporal and spatial components of kicking limb behaviour (velocity, trajectory, and distance) are a result of the magnitude and duration of muscular impulses acting on the joints, greater relative lean mass may afford accurate kickers with improved limb control in response to reduced volitional effort and lower relative impulses to generate kicking limb velocity.

Recognising the evident importance of relative lean mass illustrated in studies three and four, and the established relationship in the literature between force generation and muscle size; the fifth and final study of this thesis sought to assess the relationship between lower limb strength and kicking accuracy performance, with a secondary purpose to examine lower limb symmetry (muscularity and strength) between the kicking and support limbs of accurate and inaccurate kickers. Using the lower limb strength and leg mass methodologies established in studies one and two, this final study successfully demonstrated a positive relationship between relative bilateral strength and support-leg unilateral strength with kicking accuracy outcomes (r = 0.379 to 0.401). A significant, negative relationship was also established between strength imbalances and kicking accuracy (p = 0.002; r = 0.516), further supported by the significant, positive relationship illustrated by the limb symmetry index for lean mass quantities and kicking accuracy outcomes (p = 0.003 to 0.029; r = 0.312 to 0.402).

These findings highlight the potential benefit of greater limb symmetry for strength and muscularity in Australian Footballers as a mechanism to potentially enhance kicking accuracy, while highlighting the importance of support leg strength toward accuracy production. Given that differential stresses imposed upon athletes during training and game-based participation may generate undesirable imbalances; it appears appropriate to utilise strength and conditioning programs in addition to game-based loading as a mechanism to reduce and monitor limb imbalances, while increasing overall relative lean mass across both kicking and support limbs. This may optimise performance, minimise injury incidence or severity, and potentially enable greater kicking ability across both limbs (preferred and non-preferred); though these relationships require further research.

In summary, the overriding conclusion drawn from the collection of experimental studies presented in this thesis promotes the importance and positive influence of relative lean mass and lower body strength to kicking accuracy production during the drop punt. In particular, accurate kickers displayed greater quantities of relative lean mass and lower quantities of relative fat mass within their kicking and support limbs; and contained no significant strength or muscular imbalances between limbs; further supported by correlational analyses when applied to kicking accuracy outcomes. These characteristics collectively appear to positively adjust the biomechanical characteristics and strategies of Australian Footballers, which may subsequently lead to an improved performance of the drop punt kick. It is important to note that while these characteristics are positively associated with kicking accuracy, they do not necessarily create accurate performances; rather they might provide the athlete with an optimal and stable foundation to produce technically proficient performances.

These findings, in particular, provide a valid rationale for strength and conditioning professionals and skill acquisition coaches to properly consider an athlete's strength and body mass characteristics when attempting to improve kicking performance. Given the positive influence of multi-joint, dynamic, lower body strength and power interventions on kicking distance established in the literature; and the positive influence of lower body lean mass and strength characteristics on kicking accuracy established through-out this thesis; resistance training programs could potentially improve kicking accuracy outcomes. The precise nature of these acute cross-sectional outcomes provide a foundation for future longitudinal resistance training studies as a tool to establish interventions which may heighten athletic conditioning and technical proficiency in football sports with an express aim to improve kicking accuracy.

9.0 – CHAPTER NINE – FUTURE RESEARCH

The conclusions from this thesis resulted in several interesting findings, however, the review of the literature and presented experimental outcomes have revealed several potential areas for future research opportunities:

1) Technological advancements pertaining to body segment parameter and body composition assessments are still required. While DEXA is able to accurately and reliably assess quantities of whole body, and segmental mass components, it is limited by its 2D, frontal plane, field of view during the scan, which may be further confounded by the impact of gravity on the subsequent redistribution of mass in response to compression between the supine body and horizontal scan bed. To combat this, future studies may wish to establish methods and technology to enable standing, vertical 3D scanning and shape analysis solutions to enable measurements to transcend across more than plane of vision.

2) Despite the inability of the portable isometric squat device to reliably ascertain peak rate of force development over a 300 ms window; most rapid and dynamic sporting skills occur over much shorter time periods (80 – 150ms). Therefore, future research may wish to assess the rate of force development, and net vertical impulses produced over shorter time periods (30ms, 50ms, 90ms, 100ms, 150ms) in order to verify whether this device may be-able to reliably determine rate of force development and impulse over more practical and relevant time phases.

3) The impact of composite mass differences between accurate and inaccurate kickers requires further attention. While the speed-accuracy trade-off does not appear to explain visible differences in kicking accuracy, the impulse-variability theory might. We were only able to infer this indirectly from this thesis. Therefore, future studies may wish to quantify the muscular impulses prevalent at the hip and knee joints, in conjunction with lean mass quantities in the thigh and shanks segments when comparing accurate and inaccurate kickers to directly examine the applicability of this theory.

4) The speed of movement was unable to explain the differences in kicking accuracy production evident between accurate and inaccurate groups (a between-group analysis). However, confounding factors likely exist when comparing between groups with differences in technical ability, training history and previous practise time also impacting accuracy production. Therefore, future research may increase limb mass within subjects using resistance training interventions (a within-group analysis), while properly controlling for these potential confounding factors.

5) The nature of foot-ball contact and phase of collision between the foot and ball is of notable interest. Due to the relatively consistent air pressure of the ball (governed by game-based rules and regulations), an athlete may instead be-able to adjust the striking mass of the limb as a mechanism to manipulate the coefficient of restitution prevalent during foot-ball collision. As accurate kickers demonstrated higher lean-to-fat ratios in the shank and foot region; and as lean mass provides a more stable and rigid surface for impact relative to fat mass; future studies may wish to investigate the relationship between shank and foot mass characteristics and the coefficient of restitution prevalent during impact using a high-speed, high sampling frequency digitising method.

6) While limb symmetry profiles of muscularity and strength have been positively associated with kicking accuracy in this thesis; there is a notable lack of consensus in the literature concerning the positive or negative influences that such symmetry (or asymmetry) might hold over injury incidence and severity, or over athletic performance in other football-specific tasks, such as agility manoeuvres, jumping and landing. Future research may wish to further assess the broader influence of limb symmetry or lateral dominance across a wider range of sport specific skills.

7) Given the positive influence of multi-joint, dynamic, lower body strength and power interventions on kicking distance established in the literature; and the positive influence of lower body lean mass and strength characteristics on kicking accuracy established through-out this thesis; future studies may wish to employ longitudinal resistance training studies in order heighten understanding towards the potential influences of resistance training programs on kicking accuracy outcomes.

8) The outcomes of this thesis are presently applicable to the drop punt kick over a short distance, and to a player target. It is unknown whether these findings would translate to longer distances, or to a goal target; both of which require considerable adjustments to the biomechanical strategies employed. Future research may therefore examine the potential biomechanical modifications, and physiological impacts provided by varying distances, and varying target and accuracy constraints.

REFERENCES

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1994). Effects of different strength training regimes on moment and power generation during dynamic knee extensions. *European Journal of Applied Physiology and Occupational Physiology, 69*(5), 382-386.

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1996). Specificity of training velocity and training load on gains in isokinetic knee joint strength. *Acta Physiologica Scandinavica, 156*(2), 123-129.

Abrahamyan, D. O., Gazarian, A., & Braillon, P. M. (2008). Estimation of stature and length of limb segments in children and adolescents from whole-body dual-energy X-ray absorptiometry scans. *Pediatric Radiology, 38*(3), 311-315.

Ackland, T. R., Blanksby, B. A., & Bloomfield, J. (1988). Inertial characteristics of adolescent male body segments. *Journal of Biomechanics, 21*(4), 319-327.

Alam, F., Subic, A., Watkins, S., Naser, J., & Rasul, M. (2008). An experimental and computational study of aerodynamic properties of Rugby balls. *WSEAS Transactions on Fluid Mechanics, 3*(3), 279-286.

Alam, F., Subic, A., Watkins, S., & Smits, A. (2009). Aerodynamics of an Australian Rules Foot Ball and Rugby Ball. *Lecture Notes in Computational Science and Engineering, 72*, 103-127.

Amiri-Khorasani, M., Osman, N. A. A., & Yusof, A. (2010). Kinematics Analysis: Number of trials necessary to achieve performance stability during soccer instep kicking. *Journal of Human Kinetics, 23*, 15-20.

Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology, 96*(1), 46-52.

Andersen, T. B., Dorge, H. C., & Thomsen, F. I. (1999). Collisions in soccer kicking. *Sports Engineering, 2*, 121-125.

Andreoli, A., Monteleone, M., Van Loan, M., Promenzio, L., Tarantino, U., & De Lorenzo, A. (2001). Effects of different sports on bone density and muscle mass in highly trained athletes. *Medicine and Science in Sports and Exercise, 33*(4), 507-511.

Appleby, B., & Dawson, B. (2002). Video analysis of selected game activities in Australian Rules Football. *Journal of Science and Medicine in Sport, 5*(2), 129-142.

Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine and Science in Sports, 13*(4), 244-250.

Augustsson, J., Thomee, R., Linden, C., Folkesson, M., Tranberg, R., & Karlsson, J. (2006). Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. *Scandinavian Journal of Medicine and Science in Sports, 16*(2), 111-120.

Baczkowski, K., Marks, P., Silberstein, M., & Schneider-Kolsky, M. E. (2006). A new look into kicking a football: an investigation of muscle activity using MRI. *Australasian Radiology, 50*(4), 324-329.

Baker, J., & Ball, K. (1996). Biomechanical considerations of the drop punt. Canberra: Australian Institute of Sport.

Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology and Occupational Physiology*, *68*(4), 350-355.

Baktash, S., Hy, A., Muir, S., Walton, T., & Zhang, Y. (2009). The effects of different instep foot positions on ball velocity in place kicking. *International Journal of Sports Science and Engineering*, *3*(2), 85-92.

Ball, K. (2007a). Use of weighted balls for improving kicking for distance. *Journal of Sports Science and Medicine*, *6*(Suppl. 10), 44.

Ball, K. (2007b). Foot-ball interaction in Australian Rules football. *Journal of Sports Science and Medicine*, *6*(Suppl. 10), 46.

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics*,*7*(1), 10-23.

Ball, K., Smith, J., & MacMahon, C. (2010). *Kick impact characteristics of junior kickers.* Paper presented at the 28th International Conference on Biomechanics in Sport, Michigan, USA.

Ball, K. (2011). Kinematic comparison of the preferred and non-preferred foot punt kick. *Journal of Sports Sciences, 29*(14), 1545-1552.

Bangsbo, J. (1994). The physiology of soccer--with special reference to intense intermittent exercise. *Acta Physiologica Scandinavia*, *619*, 1-155.

Barfield, W. R. (1998). The biomechanics of kicking in soccer. *Clinics in Sports Medicine*, *17*(4), 711-728.

Beaumesnil, M., Chaillou, E., Wagner, A. C., Rouquette, A., Audran, M., & Ginies, J. L. (2011). Body composition analysis in patients with cystic fibrosis. Comparison of 3 methods: dual energy x-ray absorptiometry, bioelectrical impedance analysis, and skinfold measurements. *Archives of Paediatrics, 18*(4), 370-375.

Beilock, S., Bertenthal, B. I., Hoerger, M., & Carr, T. H. (2008). When does haste make waste? Speed-accuracy tradeoff, skill level, and the tools of the trade. *Journal of Experimental Psychology: Applied, 14*(4), 340-352.

Bennell, K., Wajswelner, H., Lew, P., Schall-Riaucour, A., Leslie, S., Plant, D., et al. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *British Journal of Sports Medicine, 32*(4), 309-314.

Bevan, H. R., Bunce, P. J., Owen, N. J., Bennett, M. A., Cook, C. J., Cunningham, D. J., et al. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research, 24*(1), 43-47.

Bezodis, N., Trewartha, G., Wilson, C., & Irwin, G. (2007). Contributions of the non-kicking-side arm to rugby place-kicking technique. *Sports Biomechanics, 6*(2), 171-186.

Billot, M., Martin, A., Paizis, C., Cometti, C., & Babault, N. (2010). Effects of an electrostimulation training program on strength, jumping, and kicking capacities in soccer players. *Journal of Strength and Conditioning Research, 24*(5), 1407-1413.

Bioleau, R. A., & Lohman, T. H. (1977). The measurement of human physique and its effects on physical performance. *Orthopedic Clinics of North America, 8,* 563-581.

Bishop, D. (2008). An applied research model for the sports sciences. *Sports Medicine, 38*(3), 253-263.

Blazevich, A. J., Gill, N., & Newton, R. U. (2002). Reliability and validity of two isometric squat tests. *Journal of Strength and Conditioning Research, 16*(2), 298-304.

Bridge, P., Pocock, N. A., Nguyen, T., Munns, C., Cowell, C. T., & Thompson, M. W. (2009). Prediction of appendicular skeletal and fat mass in children: excellent concordance of dual-energy X-ray absorptiometry and magnetic resonance imaging. *Journal of Pediatric Endocrinology and Metabolism, 22*(9), 795-804.

Brockett, C. L., Morgan, D. L., & Proske, U. (2004). Predicting hamstring strain injury in elite athletes. *Medicine and Science in Sports and Exercise, 36*(3), 379-387.

Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine, 38*(12), 1045-1063.

Burkett, B. (2010). *Sport mechanics for coaches* (3rd ed.). Champaign, IL: Human Kinetics.

Butterfield, S. A., & Loovis, E. M. (1994). Influence of age, sex, balance, and sport participation on development of kicking by children in grades K-8. *Perceptual and Motor Skills, 79*(1 Pt 2), 691-697.

Cameron, M., & Adams, R. (2003). Kicking footedness and movement discrimination by elite Australian Rules footballers. *Journal of Science and Medicine in Sport, 6*(3), 266-274.

Campo, S. S., Vaeyens, R., Philippaerts, R. M., Redondo, J. C., Benito, A. M., & Cuadrado, G. (2009). Effects of lower-limb plyometric training on body composition, explosive strength and kicking speed in female soccer players. *Journal of Strength and Conditioning Research, 23*(6), 1714-1722.

Cardinale, M., Newton, R., & Nosaka, K. (2011). *Strength and Conditioning: Biological Principles and Practical Applications*: Wiley-Blackwell.

Cauraugh, J. H., Gabert, T. E., & White, J. J. (1990). Tennis serving velocity and accuracy. *Perceptual and Motor Skills, 70*, 719-722.

Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N. B., Cronin, J., & Chamari, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. *Journal of Sports Sciences, 27*(2), 151-157.

Chelly, M. S., Hermassi, S., & Shephard, R. J. (2010). Relationships between power and strength of the upper and lower limb muscles and throwing velocity in male handball players. *Journal of Strength and Conditioning Research, 24*(6), 1480-1487.

Clagg, S. E., Warnock, A., & Thomas, J. S. (2009). Kinetic analyses of maximal effort soccer kicks in female collegiate athletes. *Sports Biomechanics, 8*(2), 141-153.

Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J. C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *International Journal of Sports Medicine, 22*(1), 45-51.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance, 3*(2), 131-144.

Coventry, E., Ball, K., Parrington, L., Taylor, S., Aughey, R., & McKenna, M. (2011). The effect of a game-specific short term fatigue protocol on kicking in Australian Football. *Portugese Journal of Sport Sciences, 11*(Suppl. 2), 69-72.

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength Conditioning Research, 19*(2), 349-357.

Cronin, J. B., Hing, R. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research, 18*(3), 590-593.

Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Is velocity-specific strength training important in improving functional performance? *Journal of Sports Medicine and Physical Fitness, 42*(3), 267-273.

Croisier, J. L., Forthomme, B., Namurois, M. H., Vanderthommen, M., & Crielaard, J. M. (2002). Hamstring muscle strain recurrence and strength performance disorders. *American Journal of Sports Medicine, 30*(2), 199-203.

Davids, K., Lees, A., & Burwitz, L. (2000). Understanding and measuring coordination and control in kicking skills in soccer: Implications for talent identification and skill acquisition. *Journal of Sports Sciences, 18*, 703-714.

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Comparison of training activities and game demands in the Australian Football League. *Journal of Science and Medicine in Sport, 7*(3), 292-301.

Dean, M., Wu, S. W., & Maloney, L. T. (2007). Trading off speed and accuracy in rapid, goal-directed movements. *Journal of Vision, 7*(5), 1-12.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230.

Dempster, W. T. (1955). Space requirements of the seated operator. WADC Technical Report (TR-59-159). OH: Wright-Patterson Air Force Base.

Demura, S., Miyaguchi, K., Shin, S., & Uchida, Y. (2010). Effectiveness of the 1RM estimation method based on isometric squat using a back-dynamometer. *Journal Strength & Conditioning Research, 24*(10), 2742-2748.

Dichiera, A., Webster, K. E., Kuilboer, L., Morris, M. E., Bach, T. M., & Feller, J. A. (2006). Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. *Journal of Science and Medicine in Sport, 9*(4), 292-298.

Dorge, H. C., Andersen, T. B., Sorensen, H., Simonsen, E. B., Aagaard, H., Dyhre-Poulsen, P., et al. (1999). EMG activity of the iliopsoas muscle and leg kinetics during the soccer place kick. *Scandinavian Journal of Medicine and Science in Sports, 9*, 195-200.

Dorge, H. C., Anderson, T. B., Sorensen, H., & Simonsen, E. B. (2002). Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. *Journal of Sports Sciences, 20*(4), 293-299.

Dumas, R., Cheze, L., & Verriest, J. P. (2007). Adjustments to McConville et al. and Young et al. body segment inertial parameters. *Journal of Biomechanics, 40*(3), 543-553.

Durkin, J. L., & Dowling, J. J. (2003). Analysis of body segment parameter differences between four human populations and the estimation errors of four popular mathematical models. *Journal of Biomechanical Engineering, 125*(4), 515-522.

Durkin, J. L., & Dowling, J. J. (2006). Body segment parameter estimation of the human lower leg using an elliptical model with validation from DEXA. *Annals of Biomedical Engineering, 34*(9), 1483-1493.

Durkin, J. L., Dowling, J. J., & Andrews, D. M. (2002). The measurement of body segment inertial parameters using dual energy X-ray absorptiometry. *Journal of Biomechanics, 35*(12), 1575-1580.

Enoka, R. (2008), *Neuromechanics of Human Movement* (4th ed.). Champaign, IL: Human Kinetics.

Fawzy, T., Muttappallymyalil, J., Sreedharan, J., Ahmed, A., Alshamsi, S. O., Al Ali, M. S., et al. (2011). Association between Body Mass Index and Bone Mineral Density in Patients Referred for Dual-Energy X-Ray Absorptiometry Scan in Ajman, UAE. *Journal of Osteoporosis, 2011*, 1-4.

Fuller, N. J., Laskey, M. A., & Elia, M. (1992). Assessment of the composition of major body regions by dual-energy X-ray absorptiometry (DEXA), with special reference to limb muscle mass. *Clinical Physiology, 12*(3), 253-266.

Gamble, P. (2006). Implications and Applications of Training Specificity for Coaches and Athletes. *Journal of Strength and Conditioning, 28*(3), 54-58.

Ganley, K. J., & Powers, C. M. (2001). The use of dual energy X-ray absorptiometry in determining subject-specific anthropometric measures for kinetic analysis during gait. *Gait and Posture, 13*, 271-272.

Ganley, K. J., & Powers, C. M. (2004a). Anthropometric parameters in children: a comparison of values obtained from dual energy x-ray absorptiometry and cadaver-based estimates. *Gait and Posture, 19*(2), 133-140.

Ganley, K. J., & Powers, C. M. (2004b). Determination of lower extremity anthropometric parameters using dual energy X-ray absorptiometry: the influence on net joint moments during gait. *Clinical Biomechanics, 19*(1), 50-56.

Gerbino, P. G., Griffin, E. D., & Zurakowski, D. (2007). Comparison of standing balance between female collegiate dancers and soccer players. *Gait and Posture, 26*(4), 501-507.

Gissis, I., Papadopoulos, C., Kalapotharakos, V. I., Sotiropoulos, A., Komsis, G., & Manolopoulos, E. (2006). Strength and speed characteristics of elite, subelite, and recreational young soccer players. *Research in Sports Medicine, 14*(3), 205-214.

Glickman, S. G., Marn, C. S., Supiano, M. A., & Dengel, D. R. (2004). Validity and reliability of dual-energy X-ray absorptiometry for the assessment of abdominal adiposity. *Journal of Applied Physiology, 97*(2), 509-514.

Gouwanda, D., & Senanayake, S. M. (2011). Identifying gait asymmetry using gyroscopes--a cross-correlation and Normalized Symmetry Index approach. *Journal of Biomechanics, 44*(5), 972-978.

Gstottner, M., Neher, A., Scholtz, A., Millonig, M., Lembert, S., & Raschner, C. (2009). Balance ability and muscle response of the preferred and nonpreferred leg in soccer players. *Motor Control, 13*(2), 218-231.

Haaland, E., & Hoff, J. (2003). Non-dominant leg training improves the bilateral motor performance of soccer players. *Scandinavian Journal of Medicine and Science in Sports, 13*(3), 179-184.

Haarbo, J., Gotfredsen, A., Hassager, C., & Christiansen, C. (1991). Validation of body composition by dual energy X-ray absorptiometry (DEXA). *Clinical Physiology, 11*(4), 331-341.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., et al. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women Olympic weightlifters. *Journal of Strength and Conditioning Research, 19*(4), 741-748.

Haff, G. G., Stone, M. H., O'Bryant, H., Harman, E., Dinan, C., Johnson, R., et al. (1997). Force-time dependent characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research, 11*, 269-272.

Hall, S. (2007). *Basic Biomechanics* (5th ed.). New York: McGraw-Hill.

Hansen, L., Bangsbo, J., Twisk, J., & Klausen, K. (1999). Development of muscle strength in relation to training level and testosterone in young male soccer players. *Journal of Applied Physiology, 87*(3), 1141-1147.

Harris, N., Cronin, J., & Keogh, J. (2007). Contraction force specificity and its relationship to functional performance. *Journal of Sports Science, 25*(2), 201-212.

Hart, N. H., Nimphius, S., Cochrane, J. L., & Newton, R. U. (2012). Reliability and validity of unilateral and bilateral isometric strength using a customised, portable apparatus. *Journal of Australian Strength and Conditioning, 20*, 61-67.

Hennig, E., Althoff, K., & Hoemme, A. (2009). Soccer footwear and ball kicking accuracy. *Footwear Science, 1*(Suppl. 1), 85-87.

Herzog, W., Nigg, B. M., Read, L. J., & Olsson, E. (1989). Asymmetries in ground reaction force patterns in normal human gait. *Medicine and Science in Sports and Exercise, 21*(1), 110-114.

Heymsfield, S. B., Smith, R., Aulet, M., Bensen, B., Lichtman, S., Wang, J., et al. (1990). Appendicular skeletal muscle mass: measurement by dual-photon absorptiometry. *American Journal of Clinical Nutrition, 52*(2), 214-218.

Hides, J., Fan, T., Stanton, W., Stanton, P., McMahon, K., & Wilson, S. (2010). Psoas and quadratus lumborum muscle asymmetry among elite Australian Football League players. *British Journal of Sports Medicine, 44*(8), 563-567.

Hinrichs, R. N. (1985). Regression equations to predict segmental moments of inertia from anthropometric measurements: an extension of the data of Chandler et al. (1975). *Journal of Biomechanics, 18*(8), 621-624.

Hinrichs, R. N. (1990). Adjustments to the segment center of mass proportions of Clauser et al. (1969). *Journal of Biomechanics, 23*(9), 949-951.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-Activation Potentiation: Underlying physiology and implications for motor performance. *Sports Medicine, 35*(7), 585-595.

Holmes, C., Jones, R., Harland, A., & Petzing, J. (2006). Ball Launch Characteristics for Elite Rugby Union Players. *The Engineering of Sport 6, 6*, 211-216.

Hologic. (2004). QDR for Windows XP Reference Manual: Hologic Inc.

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1-15.

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Hosford, G., & Meikle, D. (2007). *The Science of Kicking: Kicking for distance and accuracy in Australian Football*. Victoria: B.I.P.E Publications Pty Ltd.

Hoshikawa, Y., Iida, T., Muramatsu, M., Nakajima, Y., Fukunaga, T., & Kanehisa, H. (2009). Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *Journal of Sports Sciences, 27*(2), 129-138.

Hoskins, W. T., & Pollard, H. (2003). Injuries in Australian Rules Football: A Review of the Literature. *Australasia Chiropractic Osteopathy, 11*(2), 49-56.

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Medicine, 41*(3), 221-232.

Huang, H. K., & Suarez, F. R. (1983). Evaluation of cross-sectional geometry and mass density distributions of humans and laboratory animals using computerized tomography. *Journal of Biomechanics, 16*(10), 821-832.

Huang, H. K., & Wu, S. C. (1976). The evaluation of mass densities of human body in vivo from CT scans. *Computers in Biology and Medicine, 6*(4), 337-343

Hubbard, M., de Mestre, N. J., & Scott, J. (2001). Dependence of release variables in the shot put. *Journal of Biomechanics, 34*(4), 449-456.

Hunter, J. P., Marshall, R. N., & McNair, P. (2004). Reliability of biomechanical variables of sprint running. *Medicine and Science in Sports and Exercise, 36*(5), 850-861.

Iga, J., George, K., Lees, A., & Reilly, T. (2009). Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals. *Scandinavian Journal of Medicine and Science in Sports, 19*(5), 714-719.

Izquierdo, M., Hakkinen, K., Gonzalez-Badillo, J. J., Ibanez, J., & Gorostiaga, E. M. (2002). Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology, 87*(3), 264-271.

Janelle, C. M. (2002). Anxiety, arousal and visual attention: a mechanistic account of performance variability. *Journal of Sports Sciences, 20*, 237-251.

Jensen, R. K. (1978). Estimation of the biomechanical properties of three body types using a photogrammetric method. *Journal of Biomechanics, 11*(8-9), 349-358.

Jensen, R. K. (1986). Body segment mass, radius and radius of gyration proportions of children. *Journal of Biomechanics, 19*(5), 359-368.

Jones, E. J., Bishop, P. A., Woods, A. K., & Green, J. M. (2008). Cross-sectional area and muscular strength: a brief review. *Sports Medicine, 38*(12), 987-994.

Kearns, C. F., Isokawa, M., & Abe, T. (2001). Architectural characteristics of dominant leg muscles in junior soccer players. *European Journal of Applied Physiology, 85*(3-4), 240-243.

Kellis, E., & Katis, A. (2007a). Biomechanical Characteristics and Determinants of Instep Soccer Kick. *Journal of Sports Science and Medicine, 6*, 154-165.

Kellis, E., & Katis, A. (2007b). The relationship between isokinetic knee extension and flexion strength with soccer kick kinematics: an electromyographic evaluation. *Journal of Sports Medicine and Physical Fitness, 47*(4), 385-395.

Kellis, E., Katis, A., & Gissis, I. (2004). Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Medicine and Science in Sports and Exercise, 36*(6), 1017-1028.

Kellis, E., Katis, A., & Vrabas, I. S. (2006). Effects of an intermittent exercise fatigue protocol on biomechanics of soccer kick performance. *Scandinavian Journal of Medicine and Science in Sports, 16*(5), 334-344.

Kellis, S., Gerodimos, V., Kellis, E., & Manou, V. (2001). Bilateral isokinetic concentric and eccentric strength profiles of the knee extensors and flexors in young soccer players. *Isokinetics and Exercise Science, 9*, 31-39.

Keogh, J. (1999). The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *Journal of Science and Medicine in Sport, 2*(2), 125-133.

Kohrt, W. M. (1998). Preliminary evidence that DEXA provides an accurate assessment of body composition. *Journal of Applied Physiology, 84*, 372-377.

Kubo, T., Muramatsu, M., Hoshikawa, Y., & Kanehisa, H. (2010). Profiles of trunk and thigh muscularity in youth and professional soccer players. *Journal of Strength and Conditioning Research, 24*(6), 1472-1479.

Landlinger, J., Stoggl, T., Lindlinger, S., Wagner, H., & Muller, E. (2011). Differences in ball speed and accuracy of tennis groundstrokes between elite and high-performance players. *European Journal of Sport Science*, 1-8.

Lee, M. K., Koh, M., Fang, A. C., Le, S. N., & Balasekaran, G. (2009a). Estimation of Body Segment Parameters Using Dual Energy Absorptiometry and 3-D Exterior Geometry. *13th International Conference on Biomedical Engineering, 23*(5), 1777-1780.

Lee, M. K., Le, N. S., Fang, A. C., & Koh, M. T. (2009b). Measurement of body segment parameters using dual energy X-ray absorptiometry and three-dimensional geometry: an application in gait analysis. *Journal of Biomechanics, 42*(3), 217-222.

Lees, A., & Nolan, L. (1998). The biomechanics of soccer: a review. *Journal of Sports Sciences, 16*(3), 211-234.

Lees, A. (2002). Technique analysis in sports: a critical review. *Journal of Sports Sciences, 20*(10), 813-828.

Lees, A., Asai, T., Andersen, T. B., Nunome, H., & Sterzing, T. (2010). The biomechanics of kicking in soccer: a review. *Journal of Sports Sciences, 28*(8), 805-817.

Lees, A., & Owens, L. (2011). Early visual cues associated with a directional place kick in soccer. *Sports Biomechanics, 10*(2), 125-134.

Leigh, S., Liu, H., Hubbard, M., & Yu, B. (2010). Individualized optimal release angles in discus throwing. *Journal of Biomechanics, 43*(3), 540-545.

Lenzi, D., Cappello, A., & Chiari, L. (2003). Influence of body segment parameters and modeling assumptions on the estimate of center of mass trajectory. *Journal of Biomechanics, 36*(9), 1335-1341.

Levanon, J., & Dapena, J. (1998). Comparison of the kinematics of the full-instep and pass kicks in soccer. *Medicine and Science in Sports and Exercise, 30*(6), 917-927.

Linthorne, N., & Patel, D. (2011). Optimum projection angle for attaining maximum distance in a soccer punt kick. *Journal of Sports Science and Medicine, 10*, 203-214.

Linthorne, N. P. (2001). Optimum release angle in the shot put. *Journal of Sports Sciences, 19*(5), 359-372.

Linthorne, N. P., & Everett, D. J. (2006). Release angle for attaining maximum distance in the soccer throw-in. *Sports Biomechanics, 5*(2), 243-260.

Linthorne, N. P., Guzman, M. S., & Bridgett, L. A. (2005). Optimum take-off angle in the long jump. *Journal of Sports Sciences, 23*(7), 703-712.

Loucks, A. B. (2004). Energy balance and body composition in sports and exercise. *Journal of Sports Sciences, 22*(1), 1-14.

Lyons, M., Al-Nakeeb, Y., & Nevill, A. (2006). The impact of moderate and high intensity total body fatigue on passing accuracy in expert and novice basketball players. *Journal of Sports Science and Medicine, 5*, 215-227.

Magill, R. (2008). *Motor Learning and Control: Concepts and applications* (8th ed.). New York, NY: McGraw-Hill.

Malina, R., & Geithner, C. (2011). Body composition of young athletes. *American Journal of Lifestyle Medicine, 5*(3), 262-278.

Manabe, Y., Yokozawa, T., & Ogata, M. (2003). Effect of load variation on lower muscle activity and joint torque during parallel squats. *Japanese Journal of Physical Fitness and Sports Medicine, 52*, 89-98.

Mann, R. A., Moran, G. T., & Dougherty, S. E. (1986). Comparative electromyography of the lower extremity in jogging, running, and sprinting. *American Journal of Sports Medicine, 14*(6), 501-510.

Manolopoulos, E., Papadopoulos, C., Salonikidis, K., Katartzi, E., & Poluha, S. (2004). Strength training effects on physical conditioning and instep kick kinematics in young amateur soccer players during preseason. *Perceptual and Motor Skills, 99*(2), 701-710.

Manolopoulos, E., Papadopoulos, C., & Kellis, E. (2006). Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scandinavian Journal of Medicine and Science in Sports, 16*(2), 102-110.

Marshall, R. N., & Elliott, B. C. (2000). Long-axis rotation: the missing link in proximal-to-distal segmental sequencing. *Journal of Sports Sciences, 18*(4), 247-254.

Martin, P. E., Mungiole, M., Marzke, M. W., & Longhill, J. M. (1989). The use of magnetic resonance imaging for measuring segment inertial properties. *Journal of Biomechanics, 22*(4), 367-376.

Masuda, K., Kikuhara, N., Demura, S., Katsuta, S., & Yamanaka, K. (2005). Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. *Journal of Sports Medicine and Physical Fitness, 45*(1), 44-52.

Masuda, K., Kikuhara, N., Takahashi, H., & Yamanaka, K. (2003). The relationship between muscle cross-sectional area and strength in various isokinetic movements among soccer players. *Journal of Sports Sciences, 21*(10), 851-858.

Matsuda, S., Demura, S., & Uchiyama, M. (2008). Centre of pressure sway characteristics during static one-legged stance of athletes from different sports. *Journal of Sports Sciences, 26*(7), 775-779.

McBride, J., Cormie, P., & Deane, R. (2006). Isometric squat force output and muscle activity in stable and unstable conditions. *Journal of Strength and Conditioning Research, 20*(4), 915-918.

McConville, J. T., Churchill, T. D., Kaleps, I., Clauser, C. E., & Cuzzi, J. (1980). Anthropometric relationships of body and body segment moments of inertia. Dayton, Ohio: Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base.

McGuigan, M. R., Newton, M. J., & Winchester, J. B. (2008). Use of isometric testing in soccer players. *Journal of Australian Strength and Conditioning, 16*, 11-14.

McGuigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. *Journal of Strength and Conditioning Research, 24*(9), 2570-2573.

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science and Medicine, 7*, 101-105.

McLean, B. D., & Tumilty, D. M. (1993). Left-right asymmetry in two types of soccer kick. *British Journal of Sports Medicine, 27*(4), 260-262.

McMorris, T., Gibbs, C., Palmer, J., Payne, A., & Torpey, N. (1994). Exercise and performance of a motor skill. *Research Supplement, 15*, 23-27.

Milburn, P. (1991). Real-time 3-dimensional imaging using ultrasound. *Proceeds of the XIIIth Congress of the International Society of Biomechanics*, 1230-1231

Miller, A., Strauss, B. J., Mol, S., Kyoong, A., Holmes, P. H., Finlay, P., et al. (2009). Dual-energy X-ray absorptiometry is the method of choice to assess body composition in COPD. *Respirology, 14*(3), 411-418.

Miller, S., & Barlett, R. (1996). The relationship between basketball shooting kinematics, distance and playing position. *Journal of Sports Sciences, 14*(3), 243-253.

Mognini, M., Narici, V., Sirtori, D., & Lorenzelli, F. (1994). Isokinetic torques and kicking maximal ball velocity in young soccer players. *Journal of Sports Medicine and Physical Fitness, 34*, 357-361.

Morrissey, M. C., Harman, E. A., & Johnson, M. J. (1995). Resistance training modes: specificity and effectiveness. *Medicine and Science in Sports and Exercise, 27*(5), 648-660.

Moss, C. L., & Wright, P. T. (1993). Comparison of three methods of assessing muscle strength and imbalance ratios of the knee. *Journal of Athletic Training, 28*(1), 55-58.

Mungan, C. E. (2007). Collision of a ball with a barbell and related impulse problems. *European Journal of Physics, 28*, 563-568.

Mungiole, M., & Martin, P. E. (1990). Estimating segment inertial properties: comparison of magnetic resonance imaging with existing methods. *Journal of Biomechanics, 23*(10), 1039-1046.

Nagengast, A. J., Braun, D. A., & Wolpert, D. M. (2011). Risk sensitivity in a motor task with speed-accuracy trade-off. *Journal of Neurophysiology, 105*(6), 2668-2674.

Naito, K., Fukui, Y., & Maruyama, T. (2010). Multijoint kinetic chain analysis of knee extension during the soccer instep kick. *Human Movement Science, 29*(2), 259-276.

Nevill, A., Holder, R., & Watts, A. (2009). The changing shape of "successful" professional footballers. *Journal of Sports Sciences, 27*(5), 419-426.

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., et al. (2006). Determination of functional strength imbalance of the lower extremities. *Journal of Strength and Conditioning Research, 20*(4), 971-977.

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research, 24*(4), 885-895.

Norton, K. I., Craig, N. P., & Olds, T. S. (1999). The evolution of Australian football. *Journal of Science and Medicine in Sport, 2*(4), 389-404.

Nunome, H., Lake, M., Georgakis, A., & Stergioulas, L. K. (2006a). Impact phase kinematics of instep kicking in soccer. *Journal of Sports Sciences, 24*(1), 11-22.

Nunome, H., Ikegami, Y., Kozakai, R., Apriantono, T., & Sano, S. (2006b). Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *Journal of Sports Sciences, 24*(5), 529-541.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707.

Ooi, C. H., Tan, A., Ahmad, A., Kwong, K. W., Sompong, R., Ghazali, K. A., et al. (2009). Physiological characteristics of elite and sub-elite badminton players. *Journal of Sports Sciences, 27*(14), 1591-1599.

Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *American Journal of Sports Medicine, 25*(1), 81-85.

Orchard, J., Walt, S., McIntosh, A., & Garlick, D. (1999). Muscle activity during the drop punt kick. *Journal of Sports Sciences, 17*(10), 837-838.

Orloff, H., Sumida, B., Chow, J., Habibi, L., Fujino, A., & Kramer, B. (2008). Ground reaction forces and kinematics of plant leg position during instep kicking in male and female collegiate soccer players. *Sports Biomechanics, 7*(2), 238-247.

O'Shea, K., & O'Shea, J. (1989). Functional Isometric Weight Training: Its effects on Dynamic and Static strength. *Journal of Applied Sport Science Research, 3*(2), 30-33.

Paillard, T., Noe, F., Riviere, T., Marion, V., Montoya, R., & Dupui, P. (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic Training, 41*(2), 172-176.

Paulus, D. C., Reiser, R. F., 2nd, & Troxell, W. O. (2004). Pneumatic strength assessment device: design and isometric measurement. *Biomedical Sciences Instrumentation, 40*, 277-282.

Pavely, S., Adams, R., Francesco, T., Larkham, S., & Maher, C. (2010). Bilateral clearance punt kicking in rugby union: Effects of hand used for ball delivery. *International Journal of Performance Analysis of Sport, 10*, 187-196.

Pavol, M. J., Owings, T. M., & Grabiner, M. D. (2002). Body segment inertial parameter estimation for the general population of older adults. *Journal of Biomechanics, 35*(5), 707-712.

Pearsall, D. J., & Costigan, P. A. (1999). The effect of segment parameter error on gait analysis results. *Gait and Posture, 9*(3), 173-183.

Pearsall, D. J., & Reid, J. G. (1994). The study of human body segment parameters in biomechanics. An historical review and current status report. *Sports Medicine, 18*(2), 126-140.

Pearsall, D. J., Reid, J. G., & Livingston, L. A. (1996). Segmental inertial parameters of the human trunk as determined from computed tomography. *Annals of Biomedical Engineering, 24*(2), 198-210.

Pearsall, D. J., Reid, J. G., & Ross, R. (1994). Inertial properties of the human trunk of males determined from magnetic resonance imaging. *Annals of Biomedical Engineering, 22*(6), 692-706.

Peiffer, J. J., Galvao, D. A., Gibbs, Z., Smith, K., Turner, D., Foster, J., et al. (2010). Strength and functional characteristics of men and women 65 years and older. *Rejuvenation Research, 13*(1), 75-82.

Perez-Gomez, J., Olmedillas, H., Delgado-Guerra, S., Ara, I., Vicente-Rodriguez, G., Ortiz, R. A., et al. (2008a). Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football. *Applied Physiology, Nutrition and Metabolism, 33*(3), 501-510.

Perez-Gomez, J., Rodriguez, G. V., Ara, I., Olmedillas, H., Chavarren, J., Gonzalez-Henriquez, J. J., et al. (2008b). Role of muscle mass on sprint performance: gender differences? *European Journal of Applied Physiology, 102*(6), 685-694.

Phillips, E., Portus, M., Davids, K., & Renshaw, I. (2011). Performance accuracy and functional variability in elite and developing fast bowlers. *Journal of Science and Medicine in Sport*.

Pietrobelli, A., Formica, C., Wang, Z., & Heymsfield, S. B. (1996). Dual-energy X-ray absorptiometry body composition model: review of physical concepts. *American Journal of Physiology, 271*(Endocinol. Metab.), E941-951.

Putnam, C. A. (1991). A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Medicine and Science in Sports and Exercise, 23*(1), 130-144.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics, 26*(Suppl. 1), 125-135.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1-2), 143-150.

Rahnama, N., Lees, A., & Bambaecichi, E. (2005). Comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics*, *48*(11-14), 1568-1575.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.

Rao, G., Amarantini, D., Berton, E., & Favier, D. (2006). Influence of body segments' parameters estimation models on inverse dynamics solutions during gait. *Journal of Biomechanics, 39*(8), 1531-1536.

Rassier, D., & MacIntosh, B. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*, 499-508.

Reid, J. G., & Jensen, R. K. (1990). Human body segment inertia parameters: a survey and status report. *Exercise and Sport Sciences Reviews, 18*, 225-241.

Reilly, T., & Doran, D. (2001). Science and Gaelic football: a review. *Journal of Sports Sciences, 19*(3), 181-193.

Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: a review. *Journal of Sports Science, 27*(6), 575-589.

Royal, K. A., Farrow, D., Mujika, I., Halson, S. L., Pyne, D., & Abernethy, B. (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. *Journal of Sports Sciences, 24*(8), 807-815.

Sadeghi, H., Allard, P., Prince, F., & Labelle, H. (2000). Symmetry and limb dominance in able-bodied gait: a review. *Gait and Posture, 12*(1), 34-45.

Saliba, L., & Hrysomallis, C. (2001). Isokinetic strength related to jumping but not kicking performance of Australian footballers. *Journal of Science and Medicine in Sport, 4*(3), 336-347.

Salonikidis, K., Amiridis, I. G., Oxyzoglou, N., de Villareal, E. S., Zafeiridis, A., & Kellis, E. (2009). Force variability during isometric wrist flexion in highly skilled and sedentary individuals. *European Journal of Applied Physiology, 107*(6), 715-722.

Schmidt, R., & Lee, T. (2005). *Motor Control and Learning: A behavioural emphasis* (4th ed.). Champaign, IL: Human Kinetics.

Schorer, J., Fath, F., Baker, J., & Jaitner, T. (2007). Identification of interindividual and intraindividual movement patterns in handball players of varying expertise levels. *Journal of Motor Behavior, 39*(5), 409-421.

Shan, G., & Westerhoff, P. (2005). Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. *Sports Biomechanics, 4*(1), 59-72.

Shaughnessy, D. (2006). Possession versus position: Strategic evaluation in AFL. *Journal of Sports Science and Medicine, 5*, 533-540.

Smith, C., Gilleard, W., Hammond, J., & Brooks, L. (2006). The application of an exploratory factor analysis to investigate the inter-relationships amongst joint movement during performance of a football skill. *Journal of Science and Medicine in Sport, 5*, 517-524.

Smith, J., Ball, K., & MacMahon, C. (2009). *Foot-to-ball interaction in preferred and non-preferred leg Australian Rules kicking.* Paper presented at the 27th International Conference on Biomechanics in Sport, Limerick, Ireland.

Sterzing, T., & Hennig, E. M. (2008). The influence of soccer shoes on kicking velocity in full-instep kicks. *Exercise and Sport Sciences Reviews, 36*(2), 91-97.

Sterzing, T., Lange, J., Wachtler, T., Muller, C., & Milani, T. (2009). *Velocity and accuracy as performance criteria for three different soccer kicking techniques.* Paper presented at the 27th International Conference on Biomechanics in Sport.

Stewart, S., Stanton, W., Wilson, S., & Hides, J. (2010). Consistency in size and asymmetry of the psoas major muscle among elite footballers. *British Journal of Sports Medicine, 44*(16), 1173-1177.

Stone, M. H., Moir, G., Glaister, M., & Sanders, R. (2002). How much strength is neccessary? *Physical Therapy in Sport*, *3*, 88-96.

Stone, M. H., O'Bryant, H. S., McCoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research, 17*(1), 140-147.

Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U. (2005). Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise, 37*(6), 1037-1043.

Teixeira, L. A. (1999). Kinematics of kicking as a function of different sources of constraint on accuracy. *Perceptual and Motor Skills, 88*(3 Pt 1), 785-789.

Theoharopoulos, A., Tsitskaris, G., Nikopoulou, M., & Tsaklis, P. (2000). Knee strength of professional basketball players. *Journal of Strength and Conditioning Research, 14*(4), 457-463.

Thorborg, K., Couppe, C., Petersen, J., Magnusson, S. P., & Holmich, P. (2011). Eccentric hip adduction and abduction strength in elite soccer players and matched controls: a cross-sectional study. *British Journal of Sports Medicine*, *45*(1), 10-13.

Tsaousidis, N., & Zatsiorsky, V. (1996). Two types of ball-effector interaction and their relative contribution to soccer kicking. *Human Movement Science, 15*, 861-876.

Tumilty, D. (1993). Physiological characteristics of elite soccer players. *Sports Medicine, 16*(2), 80-96.

Urbin, M. A., Stodden, D. F., Fischman, M. G., & Weimar, W. H. (2011). Impulse-variability theory: implications for ballistic, multijoint motor skill performance. *Journal of Motor Behavior, 43*(3), 275-283.

van den Tillaar, R., & Ettema, G. (2003). Instructions emphasizing velocity, accuracy, or both in performance and kinematics of overarm throwing by experienced team handball players. *Perceptual and Motor Skills, 97*(3 Pt 1), 731-742.

Veale, J. P., Pearce, A. J., Buttifant, D., & Carlson, J. S. (2010). Anthropometric profiling of elite junior and senior Australian football players. *International Journal of Sports Physiology and Performance, 5*(4), 509-520.

Viitasalo, J., Mononen, H., & Norvapalo, K. (2003). Release parameters at the foul line and the official result in javelin throwing. *Sports Biomechanics, 2*(1), 15-34.

Viitasalo, J. T., Saukkonen, S., & Komi, P. V. (1980). Reproducibility of measurements of selected neuromuscular performance variables in man. *Electromyography and Clinical Neurophysiology, 20*(6), 487-501.

Visser, M., Fuerst, T., Lang, T., Salamone, L., & Harris, T. B. (1999). Validity of fan-beam dual-energy X-ray absorptiometry for measuring fat-free mass and leg muscle mass. Health, Aging, and Body Composition Study--Dual-Energy X-ray Absorptiometry and Body Composition Working Group. *Journal of Applied Physiology, 87*(4), 1513-1520.

Vucetic, V., Sporis, G., & Jukic, I. (2007). Muscle strength, kicking and sprint performance parameters in elite female soccer players. *Journal of Sports Science and Medicine, 6*, 109-110.

Wagner, H., Pfusterschmied, J., Klous, M., von Duvillard, S. P., & Muller, E. (2012). Movement variability and skill level of various throwing techniques. *Human Movement Science, 31*(1), 78-90.

Wakai, M., & Linthorne, N. P. (2005). Optimum take-off angle in the standing long jump. *Human Movement Science, 24*(1), 81-96.

Wells, J. (2009). The limitations of DXA for body composition assessment. *Endocrine Abstracts, 19*, S78.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: some considerations when applying the expert performance approach. *Human Movement Science, 24*(3), 283-307.

Wilson, C., Simpson, S. E., van Emmerik, R. E., & Hamill, J. (2008). Coordination variability and skill development in expert triple jumpers. *Sports Biomechanics, 7*(1), 2-9.

Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine, 22*(1), 19-37.

Wilson, G. J., Murphy, A. J., & Walshe, A. (1996). The specificity of strength training: the effect of posture. *European Journal of Applied Physiology and Occupational Physiology, 73*(3-4), 346-352.

Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement* (2nd ed.). Toronto: John Wiley & Sons, Inc.

Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport, 13*(5), 531-536.

Witt, J. K., & Dorsch, T. E. (2009). Kicking to bigger uprights: field goal kicking performance influences perceived size. *Perception, 38*(9), 1328-1340.

Wong, P. L., Chamari, K., Chaouachi, A., Mao de, W., Wisloff, U., & Hong, Y. (2007). Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. *British Journal of Sports Medicine, 41*(2), 84-92.

Young, W. (2006). Transfer of Strength and Power Training to Sports Performance. *Journal of Sports Physiology and Performance, 2006*(1), 74-83.

Young, W., Clothier, P., Otago, L., Bruce, L., & Liddell, D. (2004). Acute effects of static stretching on hip flexor and quadriceps flexibility, range of motion and foot speed in kicking a football. *Journal of Science and Medicine in Sport, 7*(1), 23-31.

Young, W., Gulli, R., Rath, D., Russell, A., O'Brien, B., & Harvey, J. (2010). Acute effect of exercise on kicking accuracy in elite Australian football players. *Journal of Science and Medicine in Sport*, *13*(1), 85-89.

Young, W. B., Newton, R. U., Doyle, T. L., Chapman, D., Cormack, S., Stewart, G., et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules Football: a case study. *Journal of Science and Medicine in Sport, 8*(3), 333-345.

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118.

Young, W., Pryor, J., & Wilson, G. (1995). Effect of Instructions on Characteristics of Countermovement and Drop Jump Performance. *Journal of Strength and Conditioning Research, 9*(4), 232.

Young, W. B., & Rath, D. A. (2011). Enhancing Foot Velocity in Football Kicking: The Role of Strength Training. *Journal of Strength and Conditioning Research, 25*(2), 561-566.

Zakas, A. (2006). Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. *Journal of Sports Medicine and Physical Fitness, 46*(1), 28-35.

Zatsiorsky, V. M., & Seluyanov, V. M. (1985). The mass and inertia characteristics of the main segments of the human body. In H. Matsui & K. Kobayashi (Eds.), *Biomechanics VIIIB*. Champaign, IL: Human Kinetics.

APPENDIX A: International Conference on Applied Strength and Conditioning (ASCA, 2011)

RELIABILITY AND VALIDITY OF UNILATERAL AND BILATERAL ISOMETRIC STRENGTH MEASURES USING A CUSTOMISED, PORTABLE APPARATUS.

Nicolas Hart *, Sophia Nimphius, Jodie L. Cochrane, Robert U. Newton
Edith Cowan University - School of Exercise and Health Sciences – Perth, W.A., Australia

INTRODUCTION

The ability to produce high levels of muscular force and power are considered to be essential determinants in successful athletic performance across a broad range of sports [6,7,11]. While conjecture continues to exist regarding the precise levels of strength required to optimise performance [9,14], the overriding conclusion drawn from a multitude of research upholds the positive relationship between maximal strength and athletic performance [3,9,14,15]

Despite muscular expressions of strength and power remaining contextually specific [1,4,7,10], measures of isometric strength have been shown to correlate well with dynamic strength when assessed within the same exercise domain [6,14,16]. In particular, previous research has demonstrated the importance of maximal isometric strength in a variety of athletically and recreationally trained populations [2,6,9,12], using peak force [PF] and rate of force development [RFD] as descriptive measures.

Historically, these outcomes have been assessed using expensive, large-scaled, fixated devices which are limited by issues of portability, customisability, and affordability; with a notable lack of transference to training and testing scenarios [5]. It is the purpose of this paper to assess the validity and reliability of a newly created practical, portable and customisable isometric assessment device.

EXPERIMENTAL APPROACH

Maximal bilateral and unilateral lower body isometric strength measures were performed at preset hip and knee angles of 140° using both fixated and portable isometric assessment devices. Specific measures (peak force [PF], mean force [MF], rate of force development [RFD] and time to peak force [TTP]) were identified using a portable uniaxial force plate (400 series Performance Plate; Fitness Technology, Adelaide, Australia) and a data acquisition software program (Ballistic Measurement System [BMS]; Fitness Technology, Adelaide, Australia).

Figure 1. Fixated (left) and portable (right) isometric strength assessment devices comparing bilateral and unilateral squat positions.

METHODS

Subjects

Eleven recreationally trained men (age: 24.3 ± 2.2 years; body mass: 81.1 ± 10.8 kg) volunteered to participate in this study. The study was approved by Edith Cowan University's Human Ethics Committee, with written informed consent provided by all participants.

Protocol

Subjects were required to perform a total of eighteen lower body maximal isometric squat contractions, consisting of three bilateral and six unilateral (three per leg) trials on each isometric strength device (fixated and portable (Figure 1)). The order of testing between both devices for all subjects was counterbalanced, with bilateral and unilateral trial-types fully randomised [8,13]. Familiarisation was provided for both devices to accustom subjects to each apparatus. Bar height was configured to position athletes at preset hip and knee angles (Figure 2). Athletes were instructed to: "push as hard and as fast as you can, until I say stop", and were provided verbal encouragement. Each maximal trial was maintained for 5 seconds, with two minutes rest between each trial, and ten minutes rest between each apparatus. The trial which produced the greatest peak force [PF] output for each trial-type was selected for statistical analysis.

Statistical Analysis

An independent T-test ($p < 0.05$) was used to examine significant differences between each isometric device. The CV and ICC was calculated to determine reliability of measures for the portable isometric device.

Figure 2. Portable isometric testing device used to assess lower body isometric strength, demonstrating correct subject positioning from the side view. (140° hip flexion, 140° knee flexion angles).

RESULTS

The portable isometric device is highly reliable when assessing peak force (CV < 4.7%; ICC > 0.961) and mean force (CV < 9.3%; ICC > 0.831) outputs for both the bilateral & unilateral conditions. However, it is not able to reliably determine rate of force development (CV < 15.2; ICC > 0.931) in all three conditions, with noteworthy variances in the non-dominant leg (CV < 45.5; ICC > 0.360).

The portable isometric device is able to accurately measure all descriptive measures, and was successfully validated with the fixated apparatus. No significant differences ($p < 0.05$) were found between all strength outputs (peak force [PF], mean force [MF], and rate of force development [RFD]).

The only statistical difference found between the fixated and portable isometric apparatus was the time to peak force [TTPF] variable for unilateral isometric conditions only ($p < 0.001$), with each unilateral attempt requiring an extra second of time to achieve peak force.

Table 1. Reliability statistics (CV, ICC) for repeated trials using the portable isometric device.

	Bilateral Squat			Unilateral Squat [N.Dom]			Unilateral Squat [Dom]		
	PF	MF	RFD	PF	MF	RFD	PF	MF	RFD
CV	3.6	8.4	15.2	3.6	9.3	45.5	4.7	6.1	14.5
ICC	0.973	0.906	0.943	0.980	0.831	0.360	0.961	0.950	0.931

Table 2. Independent t-test statistics between each isometric apparatus [Fixated v Portable]

	Bilateral Squat				Unilateral Squat [N.Dom]				Unilateral Squat [Dom]			
	PF	MF	RFD	TTPF	PF	MF	RFD	TTPF	PF	MF	RFD	TTPF
α	0.737	0.681	0.366	0.545	0.859	0.739	0.434	0.000†	0.928	0.907	0.794	0.001†

† Statistically significant difference ($p < 0.05$) found.

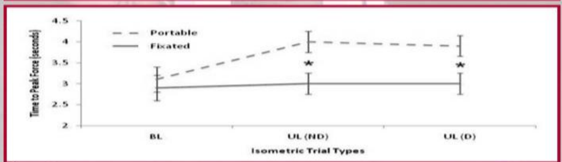


Figure 3. Time taken to produce peak force [PF] for each isometric apparatus [Fixated v Portable].

CONCLUSION

The findings of this study conclude that this new, fully customisable and portable isometric strength apparatus is a valid and reliable strength testing device. It can be used to accurately and reliably assess peak force, and mean force outputs under bilateral and unilateral testing conditions, with rate of force development measures to be interpreted with caution.

Users of this device should provide their athletes with an extra second of maximal effort during unilateral strength trials to ensure the peak is achieved; and should allow substantial familiarisation time to accommodate the athlete to the less stable condition of this new device.

PRACTICAL APPLICATION

This apparatus provides strength and conditioning professionals with an affordable, pragmatic, easy-to-administer and portable method to assess, monitor and train unilateral and bilateral lower body isometric strength at any customisable joint angle, at any time, and in any location. Future studies may wish to investigate the viability of using this apparatus for the isometric mid-thigh pull and other potential isometric assessments.

REFERENCES

[1] Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength. Eur J Appl Physiol Occup Physiol, 68(4), 350-355.
[2] Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. Sports Med, 38(12), 1045-1063.
[3] Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. J Strength Cond Res, 19(2), 349-357.
[4] Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Is velocity-specific strength training important in improving functional performance? J Sports Med Phys Fitness, 42(3), 267-273.
[5] Demura, S., Miyaguchi, K., Shin, S., & Uchida, Y. (2010). Effectiveness of the 1RM estimation method based on isometric squat using a back-dynamometer. J Strength Cond Res, 24(10), 2742-2748.
[6] Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., et al. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. J Strength Cond Res, 19(4), 741-748.
[7] Harris, N., Cronin, J., & Keogh, J. (2007). Contraction force specificity and its relationship to functional performance. J Sports Sci, 25(2), 201-212.
[8] Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-Activation Potentiation: Underlying physiology and implications for motor performance. Sports Medicine, 35(7), 585-595.
[9] McGuigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. J Strength Cond Res, 24(9), 2570-2573.
[10] Morrissey, M. C., Harman, E. A., & Johnson, M. J. (1995). Resistance training modes: specificity and effectiveness. Med Sci Sports Exerc, 27(5), 648-660.
[11] Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. J Strength Cond Res, 24(4), 885-895.
[12] O'Shea, K., & O'Shea, J. (1989). Functional Isometric Weight Training: Its effects on Dynamic and Static strength. Journal of Applied Sport Science Research, 3(2), 30-33.
[13] Rassier, D., & MacIntosh, B. (2000). Coexistence of potentiation and fatigue in skeletal muscle. Brazilian Journal of Medical and Biological Research, 33, 499-508.
[14] Stone, M. H., Moir, G., Glaister, M., & Sanders, R. (2002). How much strength is neccessary? Physical Therapy in Sport, 3, 88-96.
[15] Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U. (2005). Relationship of maximum strength to weightlifting performance. Med Sci Sports Exerc, 37(6), 1037-1043.
[16] Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. Sports Med, 22(1), 19-37.

* Corresponding Author: n.hart@ecu.edu.au

APPENDIX B: MatLAB (Velocities)

<u>Velocity - Determining Angular Velocity (Kinematics).</u>

This function is designed to calculate velocity's of joint displacements across the whole time-phase. This has been designed to run with the standard exportation of all joint angle displacement data from the Vicon Plug-in Gait model. The four columns "LElbowY" "LElbowZ" "RElbowY" "ElbowZ" need to be pre-erased before running this code. Selected joint angles / segments are included below; others can be added following the standard syntax where applicable.

Function:

```
function [ vel ] = vel ( data )
```

Sampling Frequency, Column Size, and Finish Point:

```
ColSize = size(data(:,1));
Finish = ColSize(1,1);
Freq = input('What sampling frequency was used? - Number only! -->');
Samp = 1 / Freq;
```

All 'Key' Kinematic Variables:

Additional Angles can be added using the syntax below.

```
WA = 3;
WB = 1;
while Finish >= WA
    VLHipX(WB) = (data(WA,3) - data(WB,3)) / (Samp * 2);
    VLHipY(WB) = (data(WA,4) - data(WB,4)) / (Samp * 2);
    VLKneeX(WB) = (data(WA,6) - data(WB,6)) / (Samp * 2);
    VLAnkleX(WB) = (data(WA,9) - data(WB,9)) / (Samp * 2);
    VRHipX(WB) = (data(WA,12) - data(WB,12)) / (Samp * 2);
    VRHipY(WB) = (data(WA,13) - data(WB,13)) / (Samp * 2);
    VRKneeX(WB) = (data(WA,15) - data(WB,15)) / (Samp * 2);
    VRAnkleX(WB) = (data(WA,18) - data(WB,18)) / (Samp * 2);
    VLShoulderX(WB) = (data(WA,21) - data(WB,21)) / (Samp * 2);
    VLShoulderY(WB) = (data(WA,22) - data(WB,22)) / (Samp * 2);
    VLElbowX(WB) = (data(WA,24) - data(WB,24)) / (Samp * 2);
    VRShoulderX(WB) = (data(WA,28) - data(WB,28)) / (Samp * 2);
    VRShoulderY(WB) = (data(WA,29) - data(WB,29)) / (Samp * 2);
    VRElbowX(WB) = (data(WA,31) - data(WB,31)) / (Samp * 2);
    VNeckX(WB) = (data(WA,35) - data(WB,35)) / (Samp * 2);
    VSpineX(WB) = (data(WA,41) - data(WB,41)) / (Samp * 2);
    VSpineY(WB) = (data(WA,42) - data(WB,42)) / (Samp * 2);
    VPelvisX(WB) = (data(WA,59) - data(WB,59)) / (Samp * 2);
    VPelvisY(WB) = (data(WA,60) - data(WB,60)) / (Samp * 2);
    VPelvisZ(WB) = (data(WA,61) - data(WB,61)) / (Samp * 2);
    VLFootX(WB) = (data(WA,65) - data(WB,65)) / (Samp * 2);
    VRFootX(WB) = (data(WA,68) - data(WB,68)) / (Samp * 2);
    WA = WA + 1;
    WB = WB + 1;
end
```

The next step transposes the data, so that the matrix creates columned data (not rows).

```
LHipX = VLHipX.' ;
LHipY = VLHipY.' ;
LKneeX = VLKneeX.' ;
LAnkleX = VLAnkleX.' ;
RHipX = VRHipX.' ;
RHipY = VRHipY.' ;
RKneeX = VRKneeX.' ;
RAnkleX = VRAnkleX.' ;
LShoulderX = VLShoulderX.' ;
LShoulderY = VLShoulderY.' ;
LElbowX = VLElbowX.' ;
RShoulderX = VRShoulderX.' ;
RShoulderY = VRShoulderY.' ;
RElbowX = VRElbowX.' ;
NeckX = VNeckX.' ;
SpineX = VSpineX.' ;
SpineY = VSpineY.' ;
PelvisX = VPelvisX.' ;
PelvisY = VPelvisY.' ;
PelvisZ = VPelvisZ.' ;
LFootX = VLFootX.' ;
RFootX = VRFootX.' ;
```

Velocity Outputs:

```
vel = [ LHipX LHipY LKneeX LAnkleX RHipX RHipY RKneeX RAnkleX LShoulderX
      LShoulderY LElbowX RShoulderX RShoulderY RElbowX NeckX SpineX
      SpineY PelvisX PelvisY PelvisZ LFootX RFootX ];
```

Authorship Details:

Written by Nicolas Hart
Edith Cowan University
Email: n.hart@ecu.edu.au

APPENDIX C: Human Ethics Approval

From: "Research Ethics" <research.ethics@ecu.edu.au>
Date: Monday, 8 November 2010 6:17 PM
To: "Nicolas HART" <n.hart@ecu.edu.au>
Cc: "Jodie COCHRANE" <j.cochrane@ecu.edu.au>; "Sophia NIMPHIUS" <s.nimphius@ecu.edu.au>; "Rob NEWTON" <r.newton@ecu.edu.au>; "Computing, Health and Science"
Subject: 5874 HART new approval

Dear Nicolas

Project Number: 5874 HART
Project Name: A BIOMECHANICAL AND KINANTHROPOMETRIC ANALYSIS OF THE DROP PUNT: DETERMINANTS OF KICKING ACCURACY IN AUSTRALIAN FOOTBALL.

Student Number: 10022791

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 8 November 2010 to 30 December 2011.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

Please note the following conditions of approval:
The HREC has a requirement that all approved projects are subject to monitoring conditions. This includes completion of an annual report (for projects longer than one year) and completion of a final report at the completion of the project. An outline of the monitoring conditions and the ethics report form are available from the ethics website:
http://www.ecu.edu.au/GPPS/ethics/human_ethics_resources.html

You will also be notified when a report is due.

Please feel free to contact me if you require any further information.

Regards
Kim

Kim Gifkins
Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Fax: (08) 6304 5044
Email: research.ethics@ecu.edu.au

APPENDIX D: Information Letter (All Studies)

INFORMATION LETTER TO PARTICIPANTS

A biomechanical and kinanthropometric analysis of the drop punt: Determinants of kicking accuracy in Australian Football

Chief Investigator: Nicolas Hart

School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, JOONDALUP, WA, 6027

Phone: (08) 6304 5152 , Email: n.hart@ecu.edu.au

Thank you for your expression of interest. This document provides you with details relevant to the study in which you may participate in as a subject. Please read all information contained within this letter carefully, and feel welcome to contact the chief investigator if you have any questions or concerns you wish to raise.

Purpose

The purpose of this study is to examine the full-body biomechanics of the drop punt kick, to determine the mechanical differences prevalent between skill levels and kicking accuracy. The study also aims to determine which biomechanical variables suitably influence kicking performance.

Background

Kicking is a fundamental skill, routinely employed in the sporting environment to produce effective ball progression, scoring sequences or tactical advantage. Due to the volatile nature of competitive play, a multitude of kicking strategies are employed which are broadly categorised as place kicks or punt kicks. The drop punt is a widely used kicking technique due to its accuracy and reliability, being a necessary component in any players skill-set. Skilled performance of the drop punt involves a complex interaction of many body segments, governed by intrinsic and extrinsic biomechanical factors, in order to produce accurate ball delivery over variable distances. However, limited research of the drop punt has been undertaken. Skilled kicking involves the co-ordinated behaviour of upper and lower body segments and muscles, highlighting a need for more descriptive analyses. While kinematic variables have received some attention in the literature; kinetic variables and muscle activation variables have yet to be afforded the same level of insight. This will be the first study to provide a scientific investigation to address these notable deficiencies. Specifically, this will be the first study to simultaneously collect kinematic, kinetic and electromyographic data through-out the entire drop punt kick.

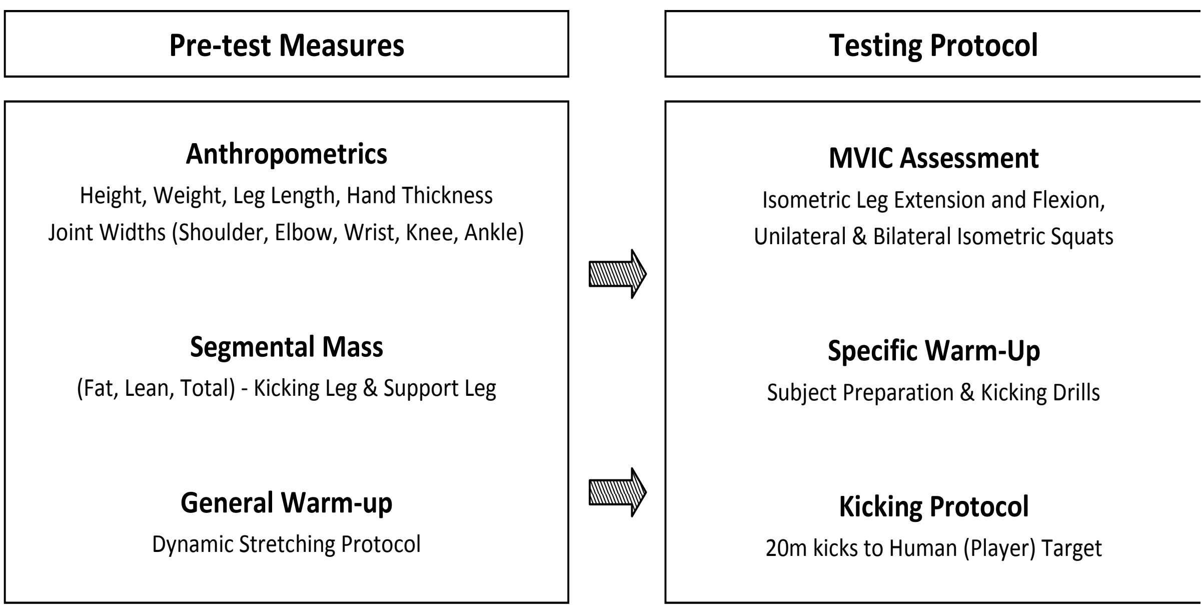
Methods

As a participant in this study, you will be required to attend one testing session for a duration of 3 hours at Edith Cowan University, Joondalup Campus, commencing in the Biomechanics Laboratory, located in Building 19, room 149. The testing session will involve a series of assessments and activities designed to assess your anthropometrics, body composition, maximal voluntary isometric strength, muscle activation levels, and kicking technique. These assessments, while primarily performed in the Biomechanics Laboratory, will also require a visit to the DEXA Laboratory and Physiology Laboratory, all located on the Joondalup Campus.

Subjects

Thirty two Australian Football athletes will be recruited for this study. You must currently participate in the AFL, WAFL or WAAFL competitions, and have done-so for at least five years, with the two most recent years at your current playing level. You must be aged between 18 and 30 years; and be void of any injuries obtained within the previous three months. You are required to wear your club issued football shorts, and will be provided with indoor training shoes. You are also required to refrain from any lower body resistance training or vigorous physical activity within 48 hours of our arranged testing session, and will be required to complete a pre-exercise medical questionnaire upon arrival. Once you have a full understanding of your proposed involvement within this study, you will be asked to sign an informed consent document.

Design



Anthropometrics

Standard anthropometric measures will be taken in order to assess your stature, body mass, segment lengths, and joint breadths and widths. In particular, your height, weight, leg length, hand thickness and joint widths will be assessed using standard equipment including a stadiometer, weight scale, joint calliper and retractable measuring tape.

Body Composition and Leg Mass

Your body composition and lower limb mass will be assessed using a dual-energy x-ray absorptiometry (DEXA) machine. This is the ‘gold standard’ for measuring body composition, and will span approximately five minutes in duration. You will be required to wear clothing free of metallic material (your club issued football shorts), and will assume a supine position (lying on your back) with your arms by your side. This will provide an accurate measure of your total mass, muscle mass, fat mass, and bone mineral density of your entire body.

General Warm-up, Specific Warm-up and Cool Down

You will be required to complete two warm-up sessions, each spanning ten minutes in duration. The general warm-up will be completed first, and will require you to perform a series of dynamic stretches and gentle cardiovascular activities as prescribed by the chief investigator. Later in the testing session, you will be asked to complete a specific warm-up consisting of five practice drop punt kicks without a ball, followed by fifteen actual drop-punt kicks with a ball, spanning 20 metres, 30 metres, and 40 metres in distance. At the conclusion of the whole testing session, you will be required to cool down by performing a series of static stretches and gentle walking activities.

Maximal Voluntary Contraction

The level of muscle activation in the lower limbs will be measured by placing small sensory pads (surface electrodes) on the skin. These will remain fixated on your skin for the remainder of the testing session, including the kicking protocol. Eight muscles will be assessed, including the Gluteus Maximus, Gluteus Medius, Rectus Femoris, Vastus Lateralis, Biceps Femoris, Gastrocnemius and Tibialis Anterior. The maximal voluntary contraction (MVC) assessment will require you to perform a maximum effort contraction against resistance whilst seated in a chair, in a stationary position; and with a rigid stationary bar placed across your shoulders in a squat position eliciting a knee angle of 140°, where you will be asked to produce a rapid maximal pushing motion against the fixated bar.

Kicking Procedures

Retroreflective markers will be placed on your skin in various locations in order to identify the head, neck, trunk, arms and legs, to enable full-body three-dimensional motion analysis. Muscle activation measures will also be taken. The kicking protocol will require you to produce ten drop punt kicks. You will start your approach from a stationary position, and perform the drop punt over 20 metres towards a human target. You will be given one minute rest periods between each kicking trial. Water will be provided through-out this procedure.

Potential Risks

Dual-energy x-ray absorptiometry (DEXA) scans emit radiation when performed. This will expose you to very low-level radiation. It is important to understand that DEXA scanning is routinely performed in the clinical setting, and produces extremely low levels of radiation dosages per scan. To assist your understanding, a single DEXA scan produces 1 – 6 µSv; a standard flight from Perth to Darwin generates 16 µSv; and daily radiation levels (at sea-level) expose us to 12 – 16 µSv. This study will only require you for one single scan, which will only expose you to an isolated, low-level dosage of 1 – 6 µSv only.

Further risks associated with this study are minimal. There is a potential for general muscle soreness in the hours or days following the testing session, due to the maximal efforts produced during isometric testing, and in response to the volume of kicking trials produced. However, due to the training status of all subjects in general, this effect would be scarcely prevalent. Lastly, there is a low risk of muscle strain. However, this is a risk any individual faces during any physical activity. The chief investigator has a bachelor degree in exercise and sport science; is a certified strength and conditioning specialist (CSCS); and holds a senior first aid certificate; which will ensure all warm-up, exercise and cool-down procedures will be programmed, implemented and monitored under appropriate supervision.

Potential Benefits

As athletes, you will be provided with an insight into the research process behind the sport science profession, and the manner in which it directly impacts your exercise, training and skill development processes in Australian Football. Further to this, your participation will facilitate the potential improvement of the drop punt kicking skill in Australian Football and other football codes. Upon request, you will be provided with your individual results specific to your level of involvement within the study. You will also be exposed to reliable, accurate and sensitive measures of your kicking mechanics, body composition and isometric strength levels free-of-charge, in contrast to what would normally exceed $1000 in assessments.

Privacy and Confidentiality

All information collected during this research is private and confidential, and will not be disclosed to any third parties without your express consent, except to meet government, legal or other regulatory authority requirements. A de-identified copy of this data may be used for other research purposes. Your anonymity will, at all times, be safeguarded. Further to this, all data collected during this study will be de-identified to all individuals, except the investigators, and will be stored on a password protected computer, and in a locked cabinet. Original data will be kept for a period of five years, and subsequently destroyed at the end of this time.

Voluntary Participation

Involvement in this study is strictly voluntary. Your decision to accept or decline participation in this project will not prejudice you in any way. During your potential involvement, you are free to withdraw your consent and discontinue at any time, again without any prejudice.

Contacting Us

If you have any questions or concerns regarding this study, you are always welcome to contact the chief investigator, Mr Nicolas Hart: 6304 2242 (office); 0402 284 459 (mobile); n.hart@ecu.edu.au (email). Alternatively, you may also contact the projects principal supervisor, Dr Jodie Cochrane: 6304 5860 (office); j.cochrane@ecu.edu.au (email). If you wish to speak to an independent person regarding any concerns or complaints about this research project, you may contact the Research Ethics Officer: 6304 2170 (office); research.ethics@ecu.edu.au (email).

APPENDIX E: Informed Consent (All Studies)

INFORMED CONSENT

I, __________________________, consent to participating in the research project entitled:

"**A biomechanical and kinanthropometric analysis of the drop punt: Determinants of kicking accuracy in Australian Football**".

I have carefully read, and clearly understand the content contained within the information letter and consent form. I agree to participate in this study, and provide my consent freely, without any undue pressure or expectation. I understand that all study procedures will be performed as outlined in the information sheet, a copy of which I have retained for my own records. I have had any and all questions answered to my satisfaction. All questionnaires pertaining to this study have been completed to the best of my knowledge. I am aware that I may choose to withdraw from this study at any stage, without any reason or prejudice.

I agree that the data collected from this study may be published, providing my name and any information containing my identity is removed. This includes data pertaining to the kinematics, kinetics, muscle activation, anthropometrics and maximal isometric contractions as outlined in the information letter.

The researcher certifies that the subject has a full understanding of the procedures and their involvement as a participant, as outlined in this form. The subject has provided verbal confirmation of their understanding, which meets the researchers' satisfaction prior to signing the form.

Participant Name: ________________________ **Date (DD/MM/YYYY):** ___________

Witness Name: ___________________________ **Date (DD/MM/YYYY):** ___________

Researchers Name: _______________________ **Date (DD/MM/YYYY):** ___________

Signatures:

(Participant) _______________ (Witness) _____________ (Researcher) _____________

APPENDIX F: Pre-Exercise Medical Questionnaire

PRE-EXERCISE MEDICAL QUESTIONNAIRE

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/or illness that may influence your testing and performance. Please answer all questions as accurately as possible, and if you are unsure about any aspect of this form, please ask for clarification. All information provided is strictly confidential.

Personal Details

Name: ____

Date of Birth (DD/MM/YYYY): _______________ Gender: Male / Female

PART A	YES / NO	DETAILS
1. Are you a male over 45 years, or female over 55 years, who has had a hysterectomy or are postmenopausal?	Y / N	________________
2. Are you a regular smoker, or have you quit in the last 6 months?	Y / N	________________
3. Did a close family member have heart disease or surgery, or stroke before the age of 60 years?	Y / N	________________
4. Do you have, or have you ever been told you have blood pressure above 140/90 mmHg, or do you currently take blood pressure medication?	Y / N	________________
5. Do you have, or have you ever been told you have a total cholesterol level above 5.2 mmol/L (200 mg/dL)?	Y / N	________________
6. Is your BMI (weight/height^2) greater than 30?	Y / N	________________

PART B	YES / NO	DETAILS
1. Have you ever had a serious asthma attack during exercise?	Y / N	________________

2. Do you have asthma that requires medication? Y / N ____________

3. Have you had an epileptic seizure in the last 5 years? Y / N ____________

4. Do you have any moderate or severe allergies? Y / N ____________

5. Do you, or could you reasonably have an infectious disease? Y / N ____________

6. Do you, or could you reasonably have an infection or disease that might be aggravated by exercise? Y / N ____________

7. Are you, or could you reasonably be pregnant? Y / N ____________

PART C	**YES / NO**	**DETAILS**
1. Are you currently taking any prescribed or non-prescribed medication?	Y / N	____________
2. Have you had, or do you currently have any of the following:-		
➢ Rheumatic Fever	Y / N	____________
➢ Heart Abnormalities	Y / N	____________
➢ Diabetes	Y / N	____________
➢ Epilepsy	Y / N	____________
➢ Recurring back pain that will make exercise problematic, or where exercise may aggravate pain?	Y / N	____________
➢ Recurring neck pain that will make exercise problematic, or where exercise may aggravate pain?	Y / N	____________
➢ Neurological disorders that would make exercise problematic, or where exercise may aggravate the condition?	Y / N	____________
➢ Neuromuscular disorders that would make exercise problematic, or where exercise may aggravate the condition?	Y / N	____________
➢ Recurring muscle/joint injuries that would make exercise problematic, or where exercise may aggravate the condition?	Y / N	____________

- A burning or cramping sensation in your legs when walking short distances? | Y / N | ________________

- Chest discomfort, unreasonable breathlessness, dizziness or fainting, or blackouts during exercise? | Y / N | ________________

PART D	YES / NO	DETAILS
1. Have you had any influenza in the last week?	Y / N	________________
2. Do you currently have an injury that might affected, or be affected by exercise?	Y / N	________________
3. Have you had any minor or major injuries in the past 3 months? If so, please list. Has this injury stopped you training or competing in one or more sessions? If so, how many?	Y / N	________________
4. Is there any other condition not previously mentioned that may affected your ability to participate in this study?	Y / N	________________

Declaration – (to be signed in the presence of the researcher)

I acknowledge that the information provided in this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant
Name: ______________________________ Date (DD/MM/YYYY): ______________

Signature: ____

Researcher
Name: ______________________________ Date (DD/MM/YYYY): ______________

Signature: ____

Practitioner (*only if applicable*)
I, Dr ____________________________ have read the medical questionnaire and the information / consent form provided to my patient, Mr / Miss / Ms / Mrs ___________ _______________, and clear him / her medically for involvement in exercise testing.

Name: ______________________________ Date (DD/MM/YYYY): ______________

Signature: ____

Plug-in-Gait Marker Placement