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Research Article

Leg Strength and Lean Mass Symmetry Influences Kicking Performance in Australian Football

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Abstract
Differential loading patterns during game-based participation may produce or exacerbate strength imbalances between the lower limbs. It is currently unknown whether such imbalances are functionally beneficial or detrimental to performance. This study assessed the influence of lower limb strength and lean mass symmetry on kicking accuracy in Australian Football. Thirty-one Australian footballers were required to perform a kicking assessment, producing ten drop punt kicks over twenty metres to a player target. Athletes were subsequently separated into accurate (n = 15) and inaccurate (n = 16) groups, with lower-body lean mass assessed using whole body DXA scans, and lower-body strength assessed using an isometric protocol. Accurate kickers demonstrated significantly higher relative lean mass (~8% to 16%; $p = 0.001$ to 0.004) and significantly lower relative fat mass (~21% to 40%; $p = 0.001$ to 0.024) than inaccurate kickers. Accurate kickers did not contain any significant difference in lean mass or unilateral strength between lower limbs. Inaccurate kickers displayed significant asymmetry in lean mass (~3%; $p \leq 0.003$), producing significant imbalances in strength (~8%; $p \leq 0.002$) highlighting a deficiency in their support leg. Greater relative strength and improved lower limb symmetry in strength and muscularity could increase the capacity of an athlete to be technically proficient in favour of greater accuracy.

Key words: Laterality, muscularity, unilateral, imbalance, asymmetry, strength, dominance.

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 et al., 2005; 2010). 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 et al., 2009). However, in the absence of sufficient physical development, 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 et al., 2010; Newton et al., 2006), potentially facilitating or diminishing performance outcomes.

In football sports, kicking is the most important and widely used skill, 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 and Rath, 2011). 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). As the kicking skill places considerably different demands on the kicking and support limbs during task execution (Baczkowski et al., 2006; Hides et al., 2010; Nunome et al., 2006; Young and Rath, 2011), the regularity of kicking performance may uniquely and specifically develop each limb preferentially for kicking and support purposes (Gstottner et al., 2009; Hart et al., 2013; Hoshikawa et al., 2009; Kearns et al., 2001; Newton et al., 2006; Sadeghi et al., 2000; Stewart et al., 2010).

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 (Hides et al., 2010; Hoshikawa et al., 2009; Iga et al., 2009; Kearns et al., 2001; Kubo et al., 2010; Masuda et al., 2003; 2005; Rahnama et al., 2005; Stewart et al., 2010; Thorborg et al., 2011; Veale et al., 2010; Zakas, 2006). 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 (Hides et al., 2010; Stewart et al., 2010; Thorborg et al., 2011), 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 (Hart et al., 2013; Newton et al., 2006). 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; Newton et al., 2006; Veale et al., 2010; 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 kicking accu-

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racy is critically important in football sports (Dichiera et al., 2006; Hart et al., 2013; Young et al., 2010), 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.

Methods

Participants

Thirty-one sub-elite Australian footballers (age: 22.1 ± 2.8 yrs; mass: 85.1 ± 13.0 kg; height: 1.81 ± 0.07 m) were recruited from the Western Australian Football League (WAFL). All athletes were competing in the highest state-level grade, within the same football team and same developmental zone; and therefore received a similar prescription of kicking practice during structured training and skills sessions for at-least five years prior to the current study, with two consecutive years of experience at their current playing level. Athletes were free from injury 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.

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 and weight, followed by an assessment of whole-body composition and lower body segmental mass characteristics (lean, fat, total) using Dual-energy X-ray Absorptiometry (DXA). Athletes were taken through a standardised general dynamic warm-up spanning ten minutes in duration, 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 kicking performance. The kicking protocol (drop punt over 20 metres) was then completed in the biomechanics laboratory. 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 kicking performance, subjects were subsequently assigned to accurate (n = 15; age: 22 ± 3 yrs; height: 1.82 ± 0.07 m; weight: 81 ± 8 kg; body fat: 11 ± 2%; kicking efficiency: 91 ± 11%) and inaccurate (n = 16; age: 23 ± 2 yrs; height: 1.81 ± 0.07 m; weight: 89 ± 15 kg; body fat: 17 ± 5%; kicking efficiency: 58 ± 16%) groups for analysis in accordance with previously established accuracy determination criteria (Hart et al, 2013). Specifically, each kick was scored 1 (accurate), 2 (moderate), and 3 (inaccurate), with all ten kicks totalled (Table 1). Athletes who scored between 10 – 18 points were classified as accurate, whereas athletes who scored between 19 – 30 points were classified as inaccurate.

Table 1. Accuracy grading and determination criteria for human target kicking outcomes.

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.

Anthropometry

Stature was recorded to the nearest 0.1 centimeter using a wall-mounted stadiometer (Model 222, Seca, Hamburg, DE), with body weight recorded to the nearest 0.1 kilogram using a standard electronic weighing scale (AE Adams CPW Plus-200, Adam Equipment Inc., CT, USA). Stature was measured three times for each subject by the same accredited exercise scientist (ESSA; Exercise & Sport Science Australia), with the average of the three trials retained for analysis (CV ≤ 0.3%; ICC ≥ 0.994).

Strength Assessment

Unilateral and bilateral lower body strength assessments were performed on both lower limbs using an isometric back squat exercise at pre-set hip and knee joint angles of 140° (Figure 1). An isometric strength test was chosen in order to safely examine total strength capacity of the lower limbs under multi-joint unilateral and bilateral conditions while also minimising neuromuscular fatigue prior to the performance of the kicking protocol. Joint angles were assessed manually using a handheld goniometer, and were chosen on the basis of positional specificity, to best correspond with maximal force production at zero velocity (Haff et al., 2005; Nuzzo et al., 2008). Particular details concerning subject positioning and exercise instruction for bilateral and unilateral isometric conditions have been previously described and illustrated with very high between-trial reliability established for bilateral (CV ≤ 3.6%; ICC ≥ 0.973) and unilateral (CV ≤ 4.7%; ICC ≥ 0.961) maximal strength assessments (Hart et al., 2012).

Figure 1. Subject positioning for bilateral and unilateral isometric strength tests.

Athletes were provided with 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 the support limb. The order of testing was randomised and counterbalanced to negate the effects of muscular potentiation or fatigue (Rassier and MacIntosh, 2000). Subjects maintained 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.

Force-time Analysis

The best trial for each isometric condition was chosen for analysis, identified by the greatest peak force output. Absolute strength (bilateral and unilateral) was represented by peak force, with relative strength determined by dividing peak force (N) by body mass (kilograms converted to Newtons). 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. The unilateral imbalance was converted to a percentage score, where a negative outcome demonstrated a degree of lateral dominance to the support leg; whereas a positive outcome demonstrated a degree of lateral dominance to the kicking leg. In addition, the bilateral deficit (BLD) was also 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.

Scan Procedure

Lower body segmental mass and full-body composition were assessed using Dual-energy X-ray Absorptiometry (Hologic Discovery A, Waltham, WA) in accordance with previously established, standardised and reliable body positioning procedures (Hart et al., 2013; 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 DXA 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 DXA scanning zone. This has been shown to produce a scan/re-scan coefficient of variation below 1% in our laboratory (Hart et al., 2013; Peiffer et al., 2010).

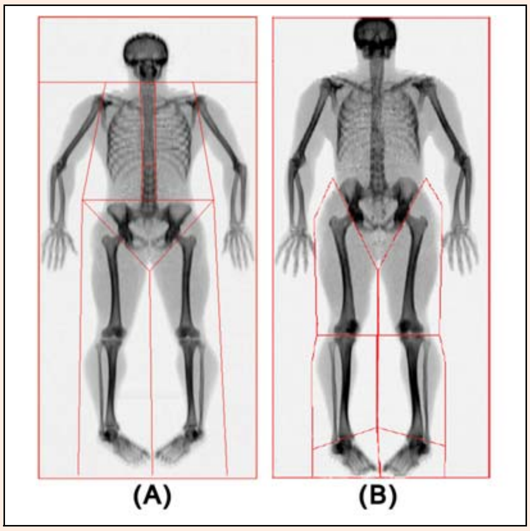

Figure 2. Boundaries employed for (A) whole-body composition and (B) lower-body segmental analysis using DXA.

Scan Analysis

Whole body scans were analysed using the inbuilt analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, WA). The predefined whole body model (Hologic, 2004) was applied to the scan image, separating the body into axial and appendicular sections to determine whole body composition. Further segmental analysis was performed to specifically quantify lower-body mass characteristics of the thigh, shank and foot regions using the sub-region analysis tool (Figure 2), explicitly defined in Table 1. Due to the extension of the lower leg segment during the kicking motion in response to fixed plantar-flexion of the foot (Orchard et al., 1997), the lower leg was defined as the shank and foot regions combined.

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 (Hart et al, 2013). 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 mass components was determined using a previously established calculation (Gouwanda and Senanayake, 2011; Sadeghi et al., 2000):

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

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), 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 meters from the centre of the kicking zone with the intention to deliver the ball as accurately as possible to the specified target. The twenty meter distance was chosen to correspond with other kicking accuracy literature in Australian Football (Dichiera et al., 2006; Hart et al., 2013; Young et al., 2010), 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 (Hart et al., 2013).

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). Ten official drop punt trials were then completed with a one minute recovery provided between each kick. For the trial to be considered valid, 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 valid kicks were produced. Angle of approach was not standardised, however all athletes voluntarily self-selected a straight approach to the target.

Accuracy Determination

Kicking accuracy was assessed using a numerical scoring system (Hart et al., 2013). All kicks were visually graded immediately following each trial by the lead researcher, the human target 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 efficiency 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 $\leq$ 1.6%; ICC $\geq$ 0.997), very high inter-tester reliability (CV $\leq$ 3.3%; ICC $\geq$ 0.986) and very high between-day reliability of kicking performance (CV $\leq$ 4.2%; ICC $\geq$ 0.975).

Statistical Analysis

All statistical computations were performed using a statistical analysis program (SPSS, Version 17.0; Chicago, IL). Quantile-quantile plots and box plots were used to assess normality. The data was normally distributed; therefore independent t-tests were used to determine whether significant differences were evident between subject characteristics, leg mass characteristics and leg strength characteristics of accurate and inaccurate kicking groups. 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): $r \geq 0.30$ is moderate; $r \geq 0.50$ is strong; $r \geq 0.70$ is very strong; $r \geq 0.90$ is nearly perfect; and $r \geq 1.00$ is perfect. Cohen's d effect size was also calculated with the magnitude of effect classified in accordance to Hopkins (2002): $d \geq 0.2$ is small; $d \geq 0.6$ is moderate; $d \geq 1.2$ is large; $d \geq 2.0$ is very large and $d \geq 4.0$ is nearly perfect.

Results

Limb Strength

Leg strength characteristics are presented in Table 3. A significant difference in strength imbalance was evident between groups (p = 0.002), with inaccurate kickers demonstrating an 8% strength deficit (asymmetry) in their support leg. This interaction was additionally supported

Table 2. Appendicular segmental boundary definitions for lower-body analysis using DXA

Segment	Proximal End	Distal End	Regional Description
Thigh	Femoral Head	Tibiofemoral Joint	Commences beneath the head of the Femur along the line of the anterior superior iliac spine (ASIS) and inferior ramus of the pubis; Ending through knee axis, noted by 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.

Table 3. Strength characteristics of accurate and inaccurate groups, presented as mean (±SD).

		Accurate (n = 15)	Inaccurate (n = 16)	Diff (%)	ES (*d*)
Absolute Strength	**[BL] – Bilateral (N)**	2473 (475)	2352 (770)	5% [c]	.2 [d]
	[SL] – Unilateral (N)	1914 (426)	1769 (531)	8% [c]	.3 [d]
	[KL] – Unilateral N)	1871 (389)	1887 (545)	1%	.0
Relative Strength	**[BL] – Bilateral (N)**	3.1 (.5)	2.8 (.9)	12% [b]	.5 [d]
	[SL] – Unilateral (N)	2.4 (.5)	2.1 (.7)	14% [b]	.6 [e]
	[KL] – Unilateral N)	2.4 (.5)	2.2 (.6)	7% [c]	.3 [d]
Other Characteristics	**Strength Imbalance**	-1% (1%) [a]	8% (1%) [a]	8% [c]	.9 [e]
	Bilateral Deficit	.7 (.1)	.6 (.1)	5% [c]	.3 [d]

SL = Support; KL = Kicking.[a] Statistical significance ($p \leq 0.01$) between groups. [b] Percent difference ≥ 10% between groups.[c] Percent difference ≥ 5% between groups. [d] Small effect size (ES ≥ 0.2) between groups. Moderate effect size (ES ≥ 0.6) between groups.

by a large negative correlation (r = -0.52) between strength imbalance and kicking accuracy. Similarly, large percent differences were evident for kicking leg strength, bilateral strength and support leg strength in relative terms, with inaccurate kickers 7%, 12% and 14% weaker than accurate kickers respectively. While these did not reach statistical significance; small to moderate effect sizes (ES = 0.3 to 0.6), and small to moderate positive correlations (r = 0.25 to 0.40) were evident between kicking accuracy, relative bilateral strength and relative unilateral strength for both kicking and support limbs.

Limb Mass

Leg mass characteristics are provided in Table 4. Significant differences were evident for the thigh, lower leg and whole leg segments of both kicking and support limbs. In particular, lean mass was significantly higher ($p \leq 0.004$), and fat mass was significantly lower ($p \leq 0.024$) for accurate kickers across all segments of both limbs, with higher total relative leg mass ($p = 0.048$) in the support leg of accurate kickers. Furthermore, lean mass was positively associated with kicking accuracy, demonstrating moderate-to-very strong correlations (Kicking: r = 0.46 to 0.63; Support: r = 0.50 to 0.71), while fat mass was negatively associated with kicking accuracy, demonstrating moderate-to-strong correlations (Kicking: r = -0.43 to -0.59; Support: r = -0.53 to -0.59). The total mass of the support leg was also positively correlated with kicking accuracy (r = 0.43).

Limb Symmetry

Symmetry index scores for lean mass of the thigh, lower-leg and whole limb segments between the kicking and support legs of accurate and inaccurate kickers are provided in Figure 3. Accurate kickers demonstrated significantly smaller lean mass asymmetry (SI = -1% to 1%) than inaccurate kickers (SI = 0% to 3%), with significant differences across all segments ($p = 0.003$ to 0.029) between accurate and inaccurate kickers. The positive symmetry index outputs for inaccurate kickers illustrate lower lean mass quantities in their support limb (relative to their kicking limb). This deficiency of lean mass (4%) for inaccurate kickers corresponds with their weaker support leg (8%) noted by their unilateral strength imbalance. Moderate positive correlations (r = 0.31 to 0.41) were also seen between kicking efficiency and symmetry index scores, highlighting a potential relationship between reduced asymmetry and improved kicking performance.

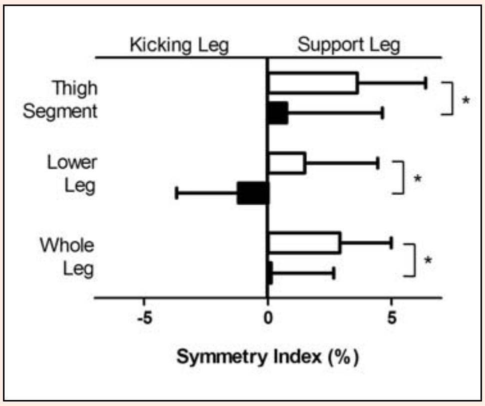

Figure 3. Lean mass imbalance of accurate (dark) and inaccurate (light) kickers, showing a deficiency (lower mass) in the kicking leg (left) and support leg (right).

Table 4. Leg mass profile of accurate (n = 15) and inaccurate (n = 16) kickers expressed as a proportion of total body mass, presented as mean (±SD); as a percentage of total body mass.

		Kicking Leg			Support Leg		
		Accurate	Inaccurate	r	Accurate	Inaccurate	r
Thigh Segment	Lean (%)	10.1 (.6)	9.4 (.8) [a]	.63 [c]	10.1 (.5)	9.0 (.8) [a]	.70 [b]
	Fat (%)	1.5 (.4)	2.4 (.8) [a]	-.58 [c]	1.4 (.4)	2.4 (.7) [a]	-.59 [c]
	Total (%)	11.9 (.4)	12.1 (.7)	.09	11.9 (.5)	11.8 (.7)	.31 [d]
Lower Leg	Lean (%)	4.7 (.3)	4.1 (.5) [a]	.46 [d]	4.7 (.3)	4.0 (.5) [a]	.50 [c]
	Fat (%)	.7 (.2)	.9 (.2) [a]	-.43 [d]	.6 (.1)	1.0 (.3) [a]	-.53 [c]
	Total (%)	5.8 (.3)	5.4 (.4) [a]	.34 [d]	5.7 (.2)	5.4 (.4) [a]	.29
Whole Leg	Lean (%)	14.8 (.7)	13.4 (1.1) [a]	.63 [c]	14.8 (.6)	13.1 (1.1) [a]	.71 [a]
	Fat (%)	2.2 (.5)	3.4 (1.0) [a]	-.59 [c]	2.0 (.5)	3.3 (1.0) [a]	-.58 [b]
	Total (%)	17.7 (.5)	17.5 (.8)	.31 [d]	17.6 (.5)	17.1 (.8) [a]	.43 [c]

[a] Statistical significance ($p \leq 0.05$) evident between accurate and inaccurate kickers. [b] Very Strong relationship (r ≥ 0.70) with kicking efficiency. [c] Strong relationship (r ≥ 0.50) with kicking efficiency. [d] Moderate relationship - (r ≥ 0.30) with kicking efficiency.

Discussion

Despite the tactical advantage provided by the ability to kick competently with both limbs (Ball, 2011), footballers tend to develop and selectively use a preferred limb for kicking, and a preferred limb for balance and support (Ball, 2011; Gstottner et al., 2009; Iga et al, 2009; Kubo et al., 2010; Zakas, 2006). Given that repetitious asymmetrical activities generate asymmetrical hypertrophic responses in muscle (Baczkowski et al., 2006; Hides et al., 2010; Stewart et al., 2010), 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; Hoshikawa et al., 2009; Kearns, et al., 2001; Kubo et al., 2010), and whether it suitably influences performance, or increases injury incidence and severity (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 strength, lower limb muscle mass and lower limb symmetry influenced drop punt kicking performance.

The primary finding of this study demonstrates a positive interaction between lower limb strength, lean mass, bilateral symmetry and kicking performance, providing support for the modification and increment of lower limb strength and muscularity in favour of greater limb symmetry. Footballers 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; produced greater levels of relative lower-body strength in bilateral and unilateral situations; and contained greater quantities of relative lean mass in all segments across both limbs. Conversely, inaccurate kickers contained significant asymmetries in lower limb muscularity (lean mass); imbalances in unilateral strength; and were relatively weaker for all strength measures. The visible imbalance and asymmetry within inaccurate kickers might demonstrate a potential deficiency in their support leg in particular - and in the lower-body more broadly - which could influence the proficient production of the kicking skill.

Footballers must adopt uni-pedal 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 (Dichiera et al., 2006; Young and Rath, 2011). 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 (reduced strength) 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 (Rahnama et al., 2005), subsequently allowing more skillful athletes to maintain balance as they powerfully strike the ball (Gstottner et al., 2009; Haines et al., 2012; Kubo et al., 2010; Matsuda et al., 2008). Therefore, the reduced magnitude of lean mass within the support leg of inaccurate kickers provides a plausible explanation for the proportionate loss of unilateral strength in the support limb. As force generation is directly related to muscle size (Hoshikawa et al., 2009; Jones et al., 2008; Perez-Gomez et al., 2008; Andersen and Aagaard, 2006), the evident strength imbalance between limbs and reduced strength capacity in the support leg may functionally limit the effective stabilisation and control of the kicking skill for inaccurate kickers and potentially explain their diminished overall performance.

Accurate kickers contained significantly greater quantities of relative lean mass in all segments across both limbs. Given the magnitude of effect and correlations for relative strength (bilateral and unilateral), and strong-to-very strong correlations of relative lean mass to kicking accuracy, it could be theorised that higher muscle mass and strength levels enable the footballer to recruit a smaller percentage of the maximum capacity of the system in order to acquire a given kicking distance. This should enable greater 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 is particularly pertinent for the kicking leg which requires high levels of rapid and dynamic co-ordination and control under complex conditions in order to strike the ball with precision (Hart et al., 2013; Lees et al., 2010; Shan and Westerhoff, 2005). Higher relative strength and lean mass values in the kicking limb of accurate kickers provides indirect support for this theory. The heightened strength capacity of the kicking leg effectively reduces the volitional effort required to produce an equivalent outcome (Haines et al., 2012; Urbin et al., 2011), thereby allowing a greater devotion of resources to limb control and mechanical adjustment (Phillips et al., 2012; Urbin et al., 2011; Wagner et al., 2012).

Although a clear difference in strength was observed between accurate and inaccurate kickers in this study; the smaller difference in the kicking leg may be a consequence of the strength assessment used (Young and Rath, 2011). Isometric strength protocols are able to represent dynamic force capabilities if the premise of positional specificity is honoured (Hart et al., 2012; Haff et al., 2005). 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 (Masuda et al., 2005; Young and Rath, 2011). This was also a limitation of the current study. Future studies measuring 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. For example, the kicking leg produces the majority of its power proximally in the segmental chain; therefore hip dominant strength and power measures could be more appropriate than isolated knee extension actions. Conversely, the support leg tolerates repetitive and rapid eccentric loads and could be examined by assessing eccentric absorption ability using drop landings or drop jumps. However, many opportunities exist in this area given the almost singular focus on isokinetic strength measures in the kicking literature to date.

Lower-body strength and muscularity can play a demonstrably positive role toward improving kicking performance (Gissis et al., 2006; Hoshikawa et al., 2009; Iga et al., 2009; Manolopoulos et al., 2006; Young and Rath, 2011). However, it is important to acknowledge that increasing strength and muscle mass alone will not necessarily improve kicking accuracy. Physical conditioning forms only one of many deterministic characteristics inherent within the kicking skill. As a result, combinations of physical and technical based interventions are considered to be most effective (Young and Rath, 2011; Manolopoulos et al., 2006). Practitioners seeking to heighten kicking accuracy are therefore encouraged to increase lower-body hypertrophy, strength and power of their footballers in addition to concurrently running skill-based kicking sessions. This serves to jointly develop the physical and biomechanical parameters necessary to increase accurate performances.

Conclusion

Greater levels of relative muscular strength, relative lean mass, and bilateral symmetry between the kicking and support limbs of football players can be used 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 all 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. 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.

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Key points

- Strength deficits in the support leg may lead to inaccurate kicking outcomes.
- An asymmetry of 3% in lean mass generated an 8% imbalance in leg strength.
- Greater levels of relative lower-body strength and muscle mass are associated with improved kicking accuracy performance.

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