Please cite the Published Version

Determining Bilateral Strength Imbalances in Youth Basketball Athletes

4 authors:

Christopher Thomas
56 PUBLICATIONS   609 CITATIONS

SEE PROFILE

Thomas Dos'Santos
Manchester Metropolitan University
66 PUBLICATIONS   508 CITATIONS

SEE PROFILE

Paul Comfort
University of Salford
215 PUBLICATIONS   2,264 CITATIONS

SEE PROFILE

Paul A Jones
University of Salford
119 PUBLICATIONS   1,351 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project   Biomechanical Assessment of Weightlifting Derivatives View project

Project   Exploring vertical jump performance in relation to modifiable and non-modifiable factors View project

Determining Bilateral Strength Imbalances in Youth Basketball Athletes

Authors
Christopher Thomas, Paul Comfort, Thomas Dos'Santos, Paul A. Jones

Affiliations
Directorate of Sport, Exercise and Physiotherapy, University of Salford, Manchester, United Kingdom of Great Britain and Northern Ireland

Correspondence
Mr. Christopher Thomas
Directorate of Sport, Exercise and Physiotherapy
University of Salford
M6 6PU, Salford, Manchester
United Kingdom of Great Britain and Northern Ireland
Tel.: +44/792/5871 029, Fax: +44/792/5871 029
c.thomas2@edu.salford.ac.uk

ABSTRACT

The aims of this study were: 1) to compare the strongest (D) and weakest (ND) limbs in determining muscle strength asymmetry (MSA) ratios among various muscle strength qualities and 2) to determine the relationships among various muscle strength qualities. 17 youth male basketball athletes (age = 17.5 ± 0.8 years; height = 187.1 ± 9.4 cm; body mass = 81.4 ± 10.1 kg) participated in this study. Knee flexor and extensor strength at $60° \cdot s^{-1}$ was assessed for both limbs with the use of isokinetic dynamometry. Other tests involved single-leg hop (SLH), countermovement jump (CMJ) and isometric mid-thigh pull (IMTP). Statistically significant differences (p < 0.05; d = 0.40-0.98) were found between D and ND limbs for all strength measures. Imbalance ratio of the IMTP was significantly related to those of SLH (r = 0.75, p = 0.01) whereas no significant relationships between D:ND ratios were found from all other tests. Percentage agreements of MSA ranged from 64.7–88.2 % between muscle strength qualities. The findings provide support for the use of field tests to detect lower-limb strength imbalances. Future research should examine the effect of different asymmetry thresholds on percentage agreements to diagnose MSA and determine its relationship to athletic performance.

Introduction

Muscle strength asymmetry (MSA) refers to the relative strength differences between limbs [26]. A strength discrepancy of ≥10–15 % between limbs is considered to represent a meaningful asymmetry [28], but it is inconclusive whether such imbalances have an impact on sports performance and the risk of injury. However, causes of MSA are multifactorial and may be due to specific unilateral sporting and or positional demands, previous injury, dominant kicking or striking limb, and limb length differences. Research attempting to classify MSA shows inconsistent results, with research classifying MSA based on limb preference [10], highest strength measure [27], and bilateral testing protocols [2]. Additionally, several methods have been proposed to calculate MSA, which subsequently elevates or reduces imbalance scores. For example, athletes who report themselves as "right limb dominant" may not truly be "right limb strength dominant" based on the test used. Additionally, MSA equations, which use the strongest (D) and weakest (ND) limbs may be misleading when analyzed longitudi-

nally, if the D limb becomes the ND through injury or in response to training and competition [8]. Several tests have previously been used to determine MSA, including isokinetic dynamometry [10], single-leg hop for distance (SLH) [30], isometric mid-thigh pull (IMTP) [14] and unilateral countermovement jump (CMJ) [29], when investigating the relationship between MSA and athletic performance. Sporting movements often require athletes to produce and accept forces in multiple planes, at various speeds, all in a fluid and ever-changing environment. Therefore, it is important for researchers and practitioners to select valid and reliable tests, which accurately assess sport-specific qualities, and to enhance these qualities through various modalities to elicit adaptations in the physical qualities required for successful sport performance.

Isokinetic dynamometry testing is commonly used to assess MSA, with recent work revealing male academy rugby union athletes to produce lower values of isokinetic peak torque on the non-preferred limb than the preferred (defined as the leg preferred to kick the ball) limb during concentric (Effect Size (ES) = 0.21–0.66)

Thomas C et al. Determining Bilateral Strength Imbalances… Int J Sports Med 2017; 38: 683–690

683

and eccentric (ES = 0.15–0.37) knee flexion and extension modes [10]. Jones and Bampouras [27] found statistically significant (p < 0.05) differences of 9–12 % in peak torque when comparing D and ND limbs during isokinetic knee extension and flexion in collegiate athletes. These findings are similar to those by Newton et al. [36] who found imbalances of 13–16 % in female softball athletes. In contrast, no statistically significant differences were found between D and ND limbs in professional basketball athletes [40]. However, the relationship of isokinetic strength MSA to dynamic performance MSA remains unclear. For example, isokinetic assessments have shown poor relationships with sprinting, jumping and changing direction [9, 12, 31]. Furthermore, although isokinetic assessments permit the quantification of torque, which is particularly useful for the screening of athletes, many would argue isokinetic assessments lack practical relevance and ecological validity to sport and exercise science.

Newton et al. [36] found a statistically significant (p < 0.05) difference in unilateral CMJ peak force (CMJ PF) between D and ND limbs, whereas Kobayashi et al. [29] found significant differences jump height (p = 0.001) and mean hip joint torque (p = 0.0468) between D and ND limbs during unilateral CMJs. In contrast, Kobayashi et al. [29] found no differences in peak and mean vertical ground reaction force. Similarly, neither study found peak force or jump height from CMJ to significantly relate to any measure of isokinetic strength. However, McElveen et al. [32] found peak vertical ground reaction force of D and ND limbs to statistically correlate to unilateral CMJ height. Previous research has established unilateral CMJ to significantly relate (r = 0.64) to unilateral horizontal jump performance in male physical education students. However, no attempt was made to quantify the association of MSA between unilateral tests. Hart et al. [22] found lean mass asymmetry was related to reductions in kicking performance in Australian Football players, whereas Bell et al. [7] found similar results showing a negative relationship between bilateral force and power asymmetry and unloaded CMJ performance. Moreover, recent studies have shown that carry-over of force production asymmetry exists in IMTP and CMJ [2–4]. However, it should be noted that population characteristics may influence MSA carry-over characteristics; therefore; implementing only one type of MSA test and attempting to infer those findings to all strength qualities may be inappropriate. Munro and Herrington [34] found mean limb symmetry index scores (dominant limb/non-dominant limb * 100) to be 100 % during SLH, indicating the there was no MSA present in male and female athletes tested. In contrast, Jones and Bampouras [27] found statistically significant (p < 0.01) differences between D and ND limbs (D leg – ND leg/D leg x 100) in collegiate athletes. Additionally, the same authors found no relationship for D:ND ratio between SLH and isokinetic quadriceps and hamstring strength. Collectively, these studies indicate that MSA is task- and-muscle strength quality dependent, and that normative data must be generated across sports and tests to determine appropriate MSA ratios.

Asymmetrical differences have been observed between D and ND limbs for IMTP peak force (IMTP PF) and time-specific force values [4], with researchers reporting larger MSA ratios in weaker athletes compared to stronger athletes, regardless of sex [4]. Furthermore, larger MSA ratios have been associated with lower jump heights in loaded and unloaded jumps [2]. However, although high-

ly valuable, IMTP testing was performed bilaterally, which does not directly assess an isolated limb's force production capabilities. Recent research has found PF recorded during unilateral stance IMTP testing performed in a custom rig to reveal statistically significant (p < 0.001) differences in IMTP PF between D and ND limbs identifying the unilateral IMTP to be able to detect MSA, in addition to assessing one's isometric force-production capabilities. Additionally, unilateral IMTP PF has also shown a strong relationship with 505 performance (r = −0.65) indicating the importance of strength of both limbs during change of direction tasks [41].

It is highly important MSA assessments that utilize similar types, magnitudes, and rates of loading specific to the mechanical variables which dictate the sport performance. Therefore, the aims of this study were: 1) to compare the strongest (D) and weakest (ND) limbs in determining muscle strength asymmetry (MSA) ratios among various muscle strength qualities and 2) to determine the relationships among various muscle strength qualities assessed in this study (concentric and eccentric knee extensor and flexor torque, unilateral stance IMTP peak force, vertical and horizontal jump performance). It was hypothesized that significant differences would be found between D and ND limbs for all tests. It was further hypothesized there would be no relationships between MSA ratios among isokinetic and functional field tests.

Materials and Methods

Participants

Young male basketball athletes (n = 17; age = 17.5 ± 0.8 years; height = 187.1 ± 9.4 cm; body mass = 81.4 ± 10.1 kg) participated in this study. All athletes provided written informed consent, with consent from the parent or guardian of all athletes under the age of 18. The study procedures were approved by the University Ethics Committee, and procedures conformed to the Declaration of Helsinki. A cross-sectional design was used to determine muscle strength imbalances of the lower limbs using isokinetic dynamometry and unilateral functional field tests such as IMTP, SLH and CMJ. For the various tests used, the performance of each leg was obtained for subsequent comparison between strength D (highest value) and ND (lowest value) limbs to examine the imbalance between limbs. Correlational analyses were conducted to determine relationships between D and ND imbalance ratios calculated from all tests. The current investigation also adhered to the standards of the International Journal of Sports Medicine described by Harriss et al. [21].

Testing procedures

Athletes attended testing on 2 separate occasions, at the same time of day, to undertake unilateral isokinetic concentric and eccentric knee extensor and flexor strength (CON EXT, ECC EXT, CON FLEX, and ECC FLEX, respectively) and isometric mid-thigh pull testing on day 1, with CMJ and SLH completed on day 2, separated by 48–72 h. The test order for either limb was counterbalanced for all tests to reduce order bias. All athletes rested the day before testing and were asked to attend testing in a fed and hydrated state, similar to their normal practices before training. All athletes were familiar with the testing procedures as part of their normal train-

ing and monitoring regime. Before the start of testing, athletes performed a standardized warm-up of activation and mobilization exercises, including various bodyweight lunges and squats, followed by some low-level plyometric drills, replicating the participant's standardized warm-ups before training. Further, standardized progressive warm-ups were applied before all tests to control potential variables and improve the reliability of all tests.

Isokinetic testing

Knee flexor and extensor muscle strength was assessed at $60°·s^{-1}$ in both concentric and eccentric modes using a Kin Com (Chattanooga Group, Tennessee) isokinetic dynamometer, as described in previous research [20]. The dynamometer was calibrated according to manufacturers' standardized procedures prior to data collection. Before measuring each leg, the motor axis of the dynamometer was visually aligned with the axis of the knee joint (midway between the lateral condyles of the femur and tibia). The cuff of the dynamometer lever arm was attached to the ankle, 5 cm proximal to the malleoli, and the moment arm recorded for gravity correction purposes. The athlete was seated and stabilized by straps so that only the knee to be tested was moving with a single degree of freedom. The back of the seat was adjusted so that hip angle was 90°. A specific warm-up of 8 submaximal (~70%) concentric knee flexion and extension movements preceded the maximal measurements. The order of tests was CON EXT, ECC EXT, ECC FLEX, CON FLEX. Peak torque was obtained from 4 maximal repetitions in each mode throughout an arc of 90° (full knee extension = 0°). The resistance provided by the weight of the lower-limb was recorded at 30° knee flexion for gravity correction purposes by adding (for extensors) or subtracting (for flexors) the gravity correction factor: [weight of leg] * [moment arm] * [cosine (angle of flexion)]. The highest peak flexion and extension torque of the 4 repetitions in each mode was used for further analysis, and was presented as a value relative to body mass ($Nm·kg^{-1}$). Data were exported in ASCII format into Microsoft Excel (version 2016, Microsoft Corp., Redmond, WA, USA) for further analysis.

Isometric testing

Unilateral stance IMTP testing was performed using a portable force platform sampling at 600 Hz (400 Series Performance Force Plate; Fitness Technology). The force platform was interfaced with computer software (BMS) that allows for direct measurement of force-time characteristics and then analyzed using the BMS software. Data were filtered using a fourth order Butterworth filter with a 16 Hz cut-off frequency. Athletes obtained self-selected knee and hip angles (knee = 130–150°; hip = 140–160°) based on the reports of previous research using bilateral stance IMTP [11] to represent the posture that they would adopt during the second pull phase of a clean pull, or the start position of a dynamic mid-thigh pull. For this test, an immovable, collarless steel bar was positioned at mid-thigh, just below the crease of the hip, to represent the start of the second pull phase of a clean pull, using a portable IMTP rig (Fitness Technology, Adelaide, Australia). The bar height could be adjusted (3 cm increments) at various heights above the force platform to accommodate different sized athletes. Once the bar height was established, the athletes stood on the force platform, and their hands were strapped to the bar in accordance with previously established

methods [39], with one foot on the force platform and the other limb unsupported and flexed 90° at the knee. Each athlete was provided 2 warm-up pulls on each limb, one at 50% and one at 75% of the athletes perceived maximum effort, separated by one minute of rest. Once body position was stabilized (verified by watching the subject and force trace), the subject was given a countdown of "3, 2, 1, Pull." Athletes performed 3 maximal IMTP on each limb, with the instruction to pull against the bar with maximal effort as quickly as possible, and push the foot down into the force platform. Each maximal isometric trial was performed for 5 s, and all athletes were given strong verbal encouragement during each trial. 2 min of rest was given between the maximal effort pulls. The maximum force of each limb recorded from the force-time curve during the 5-s IMTP trial was reported as the PF, and was presented as a value relative to body mass ($N·kg^{-1}$). The mean PF for the 3 trials was used for further analysis.

Countermovement jump testing

For the unilateral CMJ, athletes were instructed to perform a rapid eccentric phase, immediately followed by a rapid concentric phase with the intention to jump as high as possible. Countermovement jumps were performed with one foot on the force platform and the other limb unsupported and flexed 90° at the knee, the hands on the hips, and athletes were instructed to jump as high as possible and land on 2 feet. Countermovement depth was self-selected by the athletes to maximize CMJ height and ecological validity. Athletes performed 2 practice jumps, one at 50% perceived effort and one at 75% perceived effort, separated by one minute of rest, before the maximal effort trials began. Athletes performed 3 trials on each limb, with one minute of rest between trials.

Countermovement jump data were collected using a portable force platform sampling at 1 000 Hz (Kistler, Switzerland, Model 9286AA, SN 1209740). The force platform was interfaced with a laptop to allow for direct measurement of force-time characteristics, and recorded using Bioware software (Version 5.11; Kistler Instrument Corporation, Switzerland) and applied to a customized Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA). Prior to the onset of the countermovement, athletes remained stationary on the force platform for 2 s to enable an accurate measurement of bodyweight. Vertical ground reaction force data were then averaged across the first second, and the onset of the countermovement was determined when this value was reduced by 5 SDs [37]. Jump height was calculated based on the vertical velocity of the center of mass (COM) at take-off [33]. Peak force was determined from the unfiltered force-time history[32] and was presented as a value relative to body mass ($N·kg^{-1}$). The mean PF and jump height for the 3 trials was used for further analysis.

Hop testing

The SLH was used as a measure of unilateral horizontal explosive performance. A 6-m long, 15-cm wide line was marked on the floor, along the middle of which was a standard tape measure, perpendicular to the starting line. The test began with athletes placing the toes on the back of the start line, before balancing on the leg to be tested, with the hands on the hips. Athletes were instructed to use a countermovement, and no restrictions were placed on body angles attained during the preparatory phase, with the instruction to

hop as far forward as possible, taking off from one leg, before landing on the same leg. Athletes had to "stick" the landing for 2 s, with no movement of the foot or hands touching the ground, for the trial to be counted. If the subject did not do this, the trial was discarded and another was attempted. The distance was measured to the nearest 0.01 m using a standard tape measure, perpendicular from the front of the start line to the posterior aspect of the back heel at the landing. Athletes performed 3 warm-up trials on each limb, followed by 3 hops for maximal horizontal distance. The mean hop distance for the 3 trials was used for further analysis (▶ **Table 1**).

Statistical analysis

All data are presented as means (± SD). Within-session reliability of the variables was examined using the 2 way random effects model intraclass correlation coefficient (ICC), coefficient of variation (CV) and standard error of measurement (SEM). Coefficient of variation was calculated as (CV % = SD/mean * 100). The SEM was calculated using the formula: (SD(pooled) * ($\sqrt{1}$-ICC)) [42]. An ICC equal to or above 0.70 was considered acceptable [5]. Normality of data was assessed by Shapiro-Wilk's statistic and Q-Q plot analysis. Paired samples student t-tests were used to compare strength D and ND limb for each strength measure. Asymmetry index for D and ND limbs was calculated by the formula: (dominant leg – nondominant leg/dominant leg x 100). Comparisons were made for both dominant (D) and nondominant (ND) limb variables between tasks based off the highest between-limb score. Effect sizes were also calculated according to the formula Cohen's d = M1 - M2/σ pooled and interpreted as trivial (< 0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (2.0–4.0) [25]. Following this, athletes were classified into balanced, right dominant and left dominant for each variable based on the sample mean plus sample SD of the MSA [1, 19]. Agreement was determined based on like-for-like classifications of asymmetry, i. e., asymmetries in CON EXT and SLH were given a value of 1, as were balanced classifications in ECC EXT and SLH. In scenarios where one test showed an asymmetry and the other balance, this was given a zero. The percentage agreement for each variable was determined based on frequency counts of like-for-like diagnoses of asymmetry (asymmetrical and balanced) divided by the number of comparisons x 100 to see whether categorization of MSA differed between muscle strength qualities. An agreement of 75 % (i. e., agreement of 3 out of 4 athletes) was considered to identify relationships of MSA between strength qualities. Pearson's product moment correlation or nonparametric equivalent Spearman's rho was used to explore relationships among strength ratios (D:ND). Correlations were evaluated as follows: small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90 to 0.99), and perfect (1.0) [25]. To avoid Type 1 error, a Holm-Bonferroni sequential adjustment was applied as multiple separate comparisons were completed. All statistical analyses were completed using SPSS version 23 (IBM, New York, NY, USA), and statistical significance was set at p ≤ 0.05.

Results

Statistically significant differences (p < 0.05) were found when comparing D and ND limbs for all strength measures (▶ **Tables 2–5**),

▶ **Table 1** Within-session reliability of muscle strength qualities. *

Reliability Variable	Mean	SD	ICC	CV	SEM
R CON EXT (Nm·kg^{-1})	2.52	0.46	0.99	18.04	0.05
L CON EXT (Nm·kg^{-1})	2.57	0.40	0.99	15.61	0.04
R ECC EXT (Nm·kg^{-1})	3.72	0.71	0.99	18.96	0.07
L ECC EXT (Nm·kg^{-1})	3.57	0.72	0.99	20.30	0.07
R CON FLEX (Nm·kg^{-1})	1.70	0.18	0.99	10.39	0.02
L CON FLEX (Nm·kg^{-1})	1.60	0.16	0.99	9.94	0.02
R ECC FLEX (Nm·kg^{-1})	2.04	0.23	0.99	11.33	0.02
L ECC FLEX (Nm·kg^{-1})	1.94	0.28	0.99	14.15	0.03
SLH R (m)	1.69	0.26	0.97	2.90	0.04
SLH L (m)	1.68	0.23	0.94	3.43	0.06
CMJ JH R (m)	0.15	0.04	0.96	4.95	0.01
CMJ JH L (m)	0.15	0.03	0.89	5.64	0.01
IMTP PF R (N·kg^{-1})	26.67	3.38	0.88	3.92	1.22
IMTP PF L (N·kg^{-1})	26.83	3.34	0.86	4.10	1.30
CMJ PF R (N·kg^{-1})	20.13	1.65	0.87	2.68	0.45
CMJ PF L (N·kg^{-1})	20.54	1.89	0.94	2.25	0.49

* CON = concentric; ECC = eccentric; EXT = extensor; FLEX = flexor; SLH = single-leg hop; CMJ = countermovement jump; JH = jump height; IMTP = isometric mid-thigh pull; PR = peak force; L = left leg; R = right leg; ICC = intraclass correlation coefficient; CV = coefficient of variation; SEM = standard error of measurement.

with small-to-moderate effects observed (d = 0.40–0.71) (▶ **Tables 2–4**).

Spearman's rho correlation analysis revealed a statistically significant relationship in D:ND ratio between IMTP PF and SLH distance (r = 0.75; p = 0.01). However, there were no statistically significant relationships between any other tests used in the study (p > 0.05) (▶ **Table 5**).

▶ **Table 6** provides frequency counts for balanced, right and left dominant classifications for each muscle strength quality based on the MSA threshold of mean ± SD of the D:ND imbalance. ▶ **Table 7** presents the agreement in diagnosis of MSA between muscle strength qualities based on mean + SD of the D:ND imbalance, ranging from 64.7 % to 88.2 %.

Discussion

The aims of this study were: 1) to compare strongest (D) and weakest (ND) limbs in determining muscle strength asymmetry (MSA) ratios among various muscle strength qualities and 2) to determine the relationships among various muscle strength qualities (concentric and eccentric knee extensor and flexor torque, unilateral stance IMTP peak force, vertical and horizontal jump performance). In agreement with previous research [27, 36], this study indicated that statistically significant differences were found between D and ND limbs for all test measures. The present findings also suggest a very large relationship exists between N:ND ratios determined via IMTP PF and SLH, whereas no significant relationship was evident between any other isokinetic or functional field tests.

The findings of this study agree with previous research that found statistically significant differences (7–13 %) between D and ND limbs for peak torque during isokinetic knee flexion and extension in athletic individuals [27, 36]. These results are similar to those

686

Thomas C et al. Determining Bilateral Strength Imbalances… Int J Sports Med 2017; 38: 683–690

▶ **Table 2** Mean ± SD isokinetic knee extension and flexion peak torque at 60° · s⁻¹ for D and ND limbs. *

	D	ND	Imbalance (%)	p	d
CON EXT (Nm·kg⁻¹)	2.72 ± 0.42	2.37 ± 0.36	11.98 ± 11.18	0.001	0.89
CON FLEX (Nm·kg⁻¹)	1.71 ± 0.17	1.59 ± 0.15	13.11 ± 10.10	0.004	0.77
ECC EXT (Nm·kg⁻¹)	3.39 ± 0.63	3.39 ± 0.71	7.00 ± 7.21	0.001	0.75
ECC FLEX (Nm·kg⁻¹)	1.88 ± 0.23	1.88 ± 0.23	10.54 ± 7.91	0.001	0.98
* CON = concentric; ECC = eccentric; EXT = extensor; FLEX = flexor; D = dominant; ND = non-dominant.					

▶ **Table 3** Mean ± SD of horizontal and vertical jump scores for D and ND limbs. *

	D	ND	Imbalance (%)	p	d
SLH (m)	1.73 ± 0.26	1.64 ± 0.21	4.97 ± 6.81	0.027	0.40
CMJ JH (m)	0.16 ± 0.04	0.14 ± 0.03	12.26 ± 9.99	0.001	0.65
* SLH = single-leg hop; CMJ = countermovement jump; JH = jump height; D = dominant; ND = non-dominant.					

▶ **Table 4** Mean ± SD of isometric and dynamic peak force for D and ND limbs. *

	D	ND	Imbalance (%)	p	d
IMTP PF (N · kg⁻¹)	27.41 ± 3.31	26.09 ± 3.27	4.80 ± 3.63	0.001	0.40
CMJ PF (N · kg⁻¹)	20.87 ± 1.78	19.81 ± 1.63	4.98 ± 3.32	0.001	0.62
* IMTP = isometric mid-thigh pull; CMJ = countermovement jump; PF = peak force; D = dominant; ND = non-dominant.					

▶ **Table 5** Correlation coefficients for D:ND ratio in each test. *

	CON EXT	ECC EXT	CON FLEX	ECC FLEX	SLH	CMJ JH	IMTP PF	CMJ PF
CON EXT	1.00							
ECC EXT	0.12	1.00						
CON FLEX	0.27	0.39	1.00					
ECC FLEX	−0.13	0.21	0.36	1.00				
SLH	−0.40	0.04	−0.28	0.37	1.00			
CMJ JH	−0.26	0.11	−0.50	−0.20	0.28	1.00		
IMTP PF	−0.49	−0.05	−0.64	−0.04	0.75†	0.29	1.00	
CMJ PF	0.27	−0.02	−0.17	−0.30	−0.22	0.31	0.29	1.00
* CON = concentric; ECC = eccentric; EXT = extensor; FLEX = flexor; SLH = single-leg hop; CMJ = countermovement jump; JH = jump height; IMTP = isometric mid-thigh pull; PF = peak force; D = dominant; ND = non-dominant.								
† Correlation significant at p < 0.01.								

by Newton et al. [36], and Jones and Bampouras [27], who reported MSA of 6–14 %, but in contrast to those of Theoharopolous et al. [40], who found no statistically significant differences between D and ND limbs in professional basketball athletes. This inconsistency may be due to differences in calculating D and ND limbs. In the current study and work by previous authors [27, 36], the D limb was defined as the limb with the highest value, whereas Theoharopolous et al. [40] defined the D limb as the leg which subjects would kick a ball with, which may have influenced the findings as the D (stronger) limb may not reflect the dominant action in basketball, thus affecting the MSA value. Furthermore, it is suggested that asymmetries are training- and competition-history specific [6, 8], so it may be that professional basketball players are equally efficient at producing and resisting force on both limbs during single-joint isokinetic assessments, compared to youth basketball athletes.

Our findings revealed percentage imbalances of 5 % and 12 % for SLH distance and unilateral CMJ height, respectively. These results are consistent with those that found significant differences between D and ND limbs in SLH performance in high school (2 %) [35]

▶ **Table 6** Frequency counts of the diagnosis of muscle strength asymmetry based on mean + SD of the D:ND imbalance. *

	Balanced	Right	Left
CON EXT (Nm·kg⁻¹)	14	1	2
ECC EXT (Nm·kg⁻¹)	14	2	1
CON FLEX (Nm·kg⁻¹)	14	3	0
ECC FLEX (Nm·kg⁻¹)	14	2	1
SLH (m)	16	1	0
CMJ JH (m)	14	2	1
IMTP PF (N · kg⁻¹)	14	1	2
CMJ PF (N · kg⁻¹)	15	0	2
* CON = concentric; ECC = eccentric; EXT = extensor; FLEX = flexor; SLH = single-leg hop; CMJ = countermovement jump; JH = jump height; IMTP = isometric mid-thigh pull; PR = peak force			

and collegiate (4 %) athletes [27]. The percentage imbalance values for unilateral CMJ height found in the current study (12 %) agree with previous research (10–12 %) [27, 29], but contradict the find-

Thomas C et al. Determining Bilateral Strength Imbalances … Int J Sports Med 2017; 38: 683–690

687

▶ **Table 7** The agreement in diagnosis of muscle strength asymmetry between muscle strength qualities based on mean + SD of the D:ND imbalance. *

Comparison	Frequency of Agreement	% Agreement
CON EXT vs. ECC EXT	15	88.2
CON EXT vs. CON FLEX	14	82.4
CON EXT vs. ECC FLEX	13	76.5
CON EXT vs. SLH	13	76.5
CON EXT vs. CMJ JH	12	70.6
CON EXT vs. IMTP PF	11	64.7
CON EXT vs. CMJ PF	11	64.7
ECC EXT vs. CON FLEX	14	82.4
ECC EXT vs. ECC FLEX	13	76.5
ECC EXT vs. SLH	13	76.5
ECC EXT vs. CMJ JH	12	70.6
ECC EXT vs. IMTP PF	11	64.7
ECC EXT vs. CMJ PF	11	64.7
CON FLEX vs. ECC FLEX	13	76.5
CON FLEX vs. SLH	13	76.5
CON FLEX vs. CMJ JH	12	70.6
CON FLEX vs. IMTP PF	12	70.6
CON FLEX vs. CMJ PF	11	64.7
ECC FLEX vs. SLH	14	82.4
ECC FLEX vs. CMJ JH	12	70.6
ECC FLEX vs. IMTP PF	12	70.6
ECC FLEX vs. CMJ PF	12	70.6
SLH vs. CMJ JH	14	82.4
SLH vs. IMTP PF	15	88.2
SLH vs. CMJ PF	15	88.2
CMJ JH vs. IMTP PF	12	70.6
CMJ JH vs. CMJ PF	13	76.5
IMTP PF vs. CMJ PF	15	88.2

* CON = concentric; ECC = eccentric; EXT = extensor; FLEX = flexor; SLH = single-leg hop; CMJ = countermovement jump; JH = jump height; IMTP = isometric mid-thigh pull; PF = peak force; D = dominant; ND = non-dominant.

ings of McElveen et al. [32] (3 %). A possible explanation for this might be that basketball athletes may develop strength imbalances toward a muscle strength quality which reflects the characteristics of the sport, such as a unilateral CMJ which mimics the skill of a lay-up. In contrast, McElveen et al. [32] used physically active adults as subjects, which may explain the lack of statistical significance in their study. Another possible explanation for this is that in this experiment and in those by Jones and Bampouras [27] and Kobayashi et al. [29], the D limb was defined as the limb with the highest score, whereas McElveen et al. [32] defined the D limb as the preferred limb to kick a soccer ball, which may have nullified D:ND differences. Jones and Bampouras [27] explain that athletes who are "right side dominant" may be left limb strength dominant, whereas Schlumberger et al. [38] suggest against comparing preferred and non-preferred limbs, as limb dominance may lack sufficient external validity. Likewise, de Ruiter et al. [13] found no difference in unilateral squat jump height, whereas Holsgaard-Larsen

et al. [24] found no difference in unilateral CMJ height, with both defining limb dominance as the preferred kicking leg. These results may be explained by the fact that the dominant limb (preferred) may not reflect the dominant action in a particular sport. In the study by de Ruiter et al. [13], athletes participated in baseball, judo, gymnastics, volleyball, cycling, and running resulting in low homogeneity of athletic backgrounds, which may be another reason for lack of any significant differences.

The current study observed statistically significant differences between D and ND limbs for IMTP PF (5 %). These results are in accordance with recent work by Dos'Santos et al. [14] indicating 5–6 % imbalance between D and ND limbs in professional rugby league athletes and collegiate athletes. Additionally, Bailey et al. [2] found isometric asymmetrical differences between D and ND limbs, with each foot on a separate force platform during bilateral stance IMTP. However, this method is not a direct assessment of an isolated limb's isometric force production capabilities. The results of this study suggest the unilateral stance IMTP can detect lower-limb MSA in youth basketball athletes, substantiating the hypotheses of the present study. Future work should be undertaken to investigate the magnitude of MSA in relation to dynamic performance such as vertical jumping, sprinting, and COD to determine the effectiveness of the unilateral stance IMTP in strength diagnosis and rehabilitation.

In contrast to previous research [29, 32], our findings revealed statistically significant differences between D and ND limbs in unilateral CMJ PF (5 %). This result may be explained by the fact that previous research was conducted on physically active individuals whereas the current investigation used basketball athletes. It may be that basketball athletes benefit from repeatedly performing single leg jump tasks, specifically taking off on one limb more frequent than the other when performing a lay-up, a drill which is commonplace in basketball training and competition. Furlong and Harrison [18] found statistically significant differences (14 %) between preferred and non-preferred limbs in plantarflexion PF during a stretch-shortening cycle (SSC) task, which are greater than the level of imbalance reported here (5 %). This discrepancy could be attributed to the involvement of the SSC during the 2 tasks. In this study, athletes were instructed to perform a CMJ for maximum height with movement times ranging from 0.8 to 0.9 s, whereas athletes in the study by Furlong and Harrison [18] were instructed to push as hard as they could while minimizing contact time. Although Furlong and Harrison [18] did not report contact times, the task of interest has previously reported contact times of < 0.25 s [17], indicating fast SSC tasks may induce greater MSA ratios than slow SSC tasks. This theory is supported by Flanagan and Harrison [16], who found statistically significant differences (~20 %) between D and ND between drop jump and rebound jump protocols in physically active subjects.

The present study found IMTP PF had large, statistically significant relationships with SLH ($r = 0.75$, $p = 0.01$) ratios, whereas no statistically significant relationships between D:ND ratios were found from all other tests. Although these tests measure different muscle qualities, the relationships may be partly explained by SLH being heavily dependent on an athlete's ability to rapidly apply and yield unilateral force over short time intervals. Additionally, it may be the case that functional field tests such as the unilateral IMTP and SLH may be able to detect lower-limb MSA imbalances (88.2 %

688

Thomas C et al. Determining Bilateral Strength Imbalances… Int J Sports Med 2017; 38: 683–690

agreement) within the current participant population. Further research will need to be done to determine whether this remains in other sporting populations. When examining the agreement between tasks, 14 athletes were categorized as balanced, one participant was right limb dominant on both tasks, and 2 athletes were categorized as left limb dominant IMTP, but balanced during SLH. Despite this study revealing a statistically significant relationship between the D:ND ratios of these tests, these findings suggest that although agreement of MSA diagnosis is high, this may have limited impact in the strength and conditioning and clinical environment.

With the exception of IMTP and SLH, this study has been unable to demonstrate statistically significant relationships between D:ND ratios in isokinetic and functional field tests. This suggests that although functional field tests can detect MSA, their magnitude are test and muscle strength quality specific. This is likely due to the field tests involving multiple joints and antagonist co-contractions. Similarly, isokinetic assessments are limited to isolated muscle groups with a constant angular velocity, thus maybe lacking ecological validity and practical relevance. This outcome is contrary to previous studies which have suggested that carry-over of force production asymmetry exists in IMTP and CMJ [3, 4]. However, it should be noted that MSA carry-over may be population-specific. It seems possible that basketball athletes may develop strength imbalances toward a muscle strength quality which reflects the characteristics of the sport, as observed in previous studies [2–4]. Furthermore, Hewit et al. [23] found that asymmetry in one test does not predict asymmetry in another; therefore, when screening athletes, the choice of tests used and variables measured should be specific to the requirements of the sport and or positions.

Previous research has revealed inconclusive evidence as to whether MSA is associated with performance differences between limbs [30, 31]. This is due to a lack of agreement on the best approach to diagnose MSA. Previous suggestions for detecting MSA have suggested >10–15% between limbs [28]. However, MSA is dependent on the mode of assessment and muscle strength quality under investigation [8]. Aldukail et al. [1] and Graham-Smith et al. [19] have suggested the use of mean + SD of imbalance in order to determine cut-off criteria for detecting MSA, revealing differences in cut-off percentages for isokinetic, hop and vertical jump tests [1]. Lockie et al. [30] have also used the mean + (0.2 * SD) asymmetry score to evaluate whether MSA impacts change of direction performance, but found no relationship. However, the authors only investigated athletes of greater (8–13 subjects) or lower asymmetry (17–22 subjects) instead of categorizing athletes as balanced, right and left strength dominant. This study has demonstrated lower agreement in diagnosis of MSA between isokinetic dynamometry and functional field tests (64.7–76.5%), compared to higher agreement between individual functional field tests (70.6–88.2%), suggesting MSA's field tasks are reflected in 3–4 out of 5 subjects in another task. These findings may be somewhat limited by the cut-off frequency used in the current study. For example, if the current study used the mean + (0.2 * SD) asymmetry score to detect MSA [30] this may have produced different interrelationships and levels of agreement between performance tests. Future research may benefit from examining the effect of different asymmetry thresholds on percentage agreements of like-for-like

identifications and interpretations of MSA to establish the most suitable asymmetry threshold for future practice [15].

A further limitation of the study is that the use of the mean + SD imbalance criteria is based on "normative" data from the specific population under investigation, which may not be "ideal". Future research is required to gather normative data on a range of athletes from different sports in order to establish criteria to diagnose MSA for specific muscle strength qualities. Further studies that take this criterion into account will need to be undertaken to investigate the implications of MSA on performance and risk of injury.

Practical applications

This study has shown that functional field tests are able to detect lower-limb MSA between D and ND limbs in youth male basketball athletes. These findings suggest that researchers and practitioners should consider using functional field tests to determine magnitudes of MSA, so subsequent training programs may be implemented accordingly. Additionally, imbalance ratios determined from IMTP were strongly related to those from the SLH testing. Associations based on the like-for-like agreement in diagnosis of MSA was a novel approach; however, its implications for diagnosing MSA and overall relationship to athletic performance requires further examination. The findings of this study could be used to report potential cut-off imbalance ratios for youth male basketball athletes. Although the current study is based on a small sample of athletes, the findings suggest researchers and practitioners should consider assessing MSA by due consideration of the muscle strength qualities that reflect the demands of the sport.

Conclusions

The present study found statistically significant differences between D and ND limbs for all methods of assessment. Future research should focus on determining whether the magnitude of MSA, using the reported cut-off imbalances, affects injury and or performance.

Acknowledgement

Conflict of Interest

The Authors have no conflict of interest to declare.

References

[1] Aldukhail A, Jones P, Gillard H, Graham-Smith P. Clinical diagnosis of strength and power asymmetry. Biol Sport 2013; 15: 33–38

[2] Bailey C, Sato K, Alexander R, Chiang C-YH, Stone M. Isometric force production symmetry and jumping performance in collegiate athletes. J Trainol 2013; 2: 1–5

Thomas C et al. Determining Bilateral Strength Imbalances … Int J Sports Med 2017; 38: 683–690

689

[3] Bailey CA, Sato K, Burnett A, Stone MH. Carry-over of force production symmetry in athletes of differing strength levels. J Strength Cond Res 2015; 29: 3188–3196

[4] Bailey CA, Sato K, Burnett A, Stone MH. Force-production asymmetry in male and female athletes of differing strength levels. Int J Sports Physiol Perform 2015; 10: 504–508

[5] Baumgartner TA, Chung H. Confidence limits for intraclass reliability coefficients. Meas Phys Educ Exerc Sci 2001; 5: 179–188

[6] Bazyler CD, Bailey CA, Chiang C-Y, Sato K, Stone MH. The effects of strength training on isometric force production symmetry in recreationally trained males. J Trainol 2014; 3: 6–10

[7] Bell D, Sanfilippo J, Binkley N. Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. J Strength Cond Res 2014; 28: 884–891

[8] Bishop C, Read P, Chavda S, Turner A. Asymmetries of the lower limb: The calculation conundrum in strength training and conditioning. Strength Cond J 2016; 38: 27–32

[9] Blackburn J, Morrissey M. The relationship between open and closed kinetic chain strength of the lower limb and jumping performance. J Orthop Sports Phys Ther 1998; 27: 430–435

[10] Brown SR, Brughelli M, Bridgeman LA. Profiling isokinetic strength by leg preference and position in rugby union athletes. Int J Sports Physiol Perform 2016; 11: 500–507

[11] Comfort P, Jones PA, McMahon JJ, Newton R. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: Test-retest reliability. Int J Sports Physiol Perform 2015; 10: 58–63

[12] Cronin JB, Hansen KT. Strength and power predictors of sports speed. J Strength Cond Res 2005; 19: 349–357

[13] de Ruiter CJ, de Korte A, Schreven S, De Haan A. Leg dominancy in relation to fast isometric torque production and squat jump height. Eur J Appl Physiol 2010; 108: 247–255

[14] Dos'Santos T, Thomas C, Jones P, Comfort P. Assessing muscle strength asymmetry via a unilateral stance isometric mid-thigh pull. Int J Sports Physiol Perform 2016

[15] Exell TA, Gittoes MJ, Irwin G, Kerwin DG. Gait asymmetry: Composite scores for mechanical analyses of sprint running. J Biomech 2012; 45: 1108–1111

[16] Flanagan EP, Harrison AJ. Muscle dynamics differences between legs in healthy adults. J Strength Cond Res 2007; 21: 67–72

[17] Furlong L-AM, Harrison AJ. Reliability and consistency of plantarflexor stretch-shortening cycle function using an adapted force sledge apparatus. Physiol Meas 2013; 34: 437

[18] Furlong L-AM, Harrison AJ. Differences in plantarflexor function during a stretch-shortening cycle task due to limb preference. Laterality: Asymmetries of Body, Brain Cognit 2015; 20: 128–140

[19] Graham-Smith P, Al-Dukhail A, Jones P. Agreement between attributes associated with bilateral jump asymmetry. In, ISBS-Conference Proceedings Archive; 2015;

[20] Graham-Smith P, Jones PA, Comfort P. Assessment of knee flexor and extensor muscle balance. Int J Athl Ther Train 2013; 18: 1–5

[21] Harriss D, Atkinson G. Ethical standards in sport and exercise science research: 2016 update. Int J Sports Med 2015; 36: 1121–1124

[22] Hart NH, Nimphius S, Spiteri T, Newton RU. Leg strength and lean mass symmetry influences kicking performance in Australian Football. J Sports Sci Med 2014; 13: 157

[23] Hewit JK, Cronin JB, Hume PA. Asymmetry in multi-directional jumping tasks. Phys Ther Sport 2012; 13: 238–242

[24] Holsgaard-Larsen A, Jensen C, Mortensen NHM, Aagaard P. Concurrent assessments of lower limb loading patterns, mechanical muscle strength and functional performance in ACL-patients — A cross-sectional study. Knee 2014; 21: 66–73

[25] Hopkins W, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009; 41: 3

[26] Impellizzeri FM, Rampinini E, Maffiuletti N, Marcora SM. A vertical jump force test for assessing bilateral strength asymmetry in athletes. Med Sci Sports Exerc 2007; 39: 2044–2050

[27] Jones PA, Bampouras TM. A Comparison of isokinetic and functional methods of assessing bilateral strength imbalance. J Strength Cond Res 2010; 24: 1553–1558

[28] Kannus P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. Int J Sports Med 1994; 15: S11–S18

[29] Kobayashi Y, Kubo J, Matsubayashi T, Matsuo A, Kobayashi K, Ishii N. Relationship between bilateral differences in single-leg jumps and asymmetry in isokinetic knee strength. J Appl Biomech 2013; 29: 61–67

[30] Lockie RG, Callaghan SJ, Berry SP, Cooke ERA, Jordan CA, Luczo TM, Jeffriess MD. Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. J Strength Cond Res 2014; 28: 3557–3566

[31] Lockie RG, Schultz AB, Jeffriess MD, Callaghan SJ. The relationship between bilateral differences of knee flexor and extensor isokinetic strength and multi-directional speed. Isokinet Exerc Sci 2012; 20: 211–219

[32] McElveen MT, Riemann BL, Davies GJ. Bilateral comparison of propulsion mechanics during single-leg vertical jumping. J Strength Cond Res 2010; 24: 375–381

[33] Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. Meas Phys Educ Exerc Sci 2008; 12: 207–218

[34] Munro AG, Herrington LC. Between-session reliability of four hop tests and the agility T-Test. J Strength Cond Res 2011; 25: 1470–1477

[35] Myers BA, Jenkins WL, Killian C, Rundquist P. Normative data for hop tests in high school and collegiate basketball and soccer players. Int J Sports Phys Ther 2014; 9: 596–603

[36] Newton RU, Gerber A, Nimphius S, Shim JK, Doan BK, Robertson M, Pearson DR, Craig BW, Hakinnen K, Kraemer WJ. Determination of functional strength imbalance of the lower extremities. J Strength Cond Res 2006; 20: 971–977

[37] Owen NJ, Watkins J, Kilduff LP, Bevan HR, Bennett MA. Development of a criterion method to determine peak mechanical power output in a countermovement jump. J Strength Cond Res 2014; 28: 1552–1558

[38] Schlumberger A, Laube W, Bruhn S, Herbeck B, Dahlinger M, Fenkart G, Schmidtbleicher D, Mayer F. Muscle imbalances–fact or fiction? Isokinet Exerc Sci 2006; 14: 3–11

[39] Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, Newton RU. Relationship of maximum strength to weightlifting performance. Med Sci Sports Exerc 2005; 37: 1037–1043

[40] Theoharopolous A, Tsitskaris G, Tsaklis P. Knee Strength of Professional Basketball Players. J Strength Cond Res 2000; 14: 457–463

[41] Thomas C, Dos'Santos T, Comfort PA, Jones P. Relationship between isometric strength, sprint, and change of direction speed in male academy cricketers. J Trainol 2016; 5: 18–23

[42] Thomas JR, Nelson JK, Silverman SJ. Research methods in physical activity. Champaign, IL: Human Kinetics; 2010

690

Thomas C et al. Determining Bilateral Strength Imbalances… Int J Sports Med 2017; 38: 683–690