

Article

Relationship between Asymmetries Measured on Different Levels in Elite Basketball Players

Filip Ujaković ^{1,2,*}  and Nejc Šarabon ^{3,4} 

¹ Department of Kinesiology of Sports, Faculty of Kinesiology, University of Zagreb, 10110 Zagreb, Croatia

² Basketball Club Cedevita Olimpija Ljubljana, 1000 Ljubljana, Slovenia

³ Faculty of Health Sciences, University of Primorska, 6310 Izola, Slovenia; nejc.sarabon@fvz.upr.si

⁴ Laboratory for Motor Control and Motor Behavior, Science to Practice, Ltd., S2P, 1000 Ljubljana, Slovenia

* Correspondence: fujakovic@gmail.com

Abstract: In this study, we investigated the association of magnitude and agreement in direction between asymmetries measured on single-joint (hip and trunk), complex movement (jumping), and skill (change of direction (CoD)) levels. The study sample comprised 43 junior- and senior-level (age = 20.5 ± 6.0 years; height = 194.5 ± 7.2 cm; body mass = 86.8 ± 10.1 kg) elite male basketball players. Both limbs/sides were tested in hip and trunk isometric strength; passive range of motion (RoM); unilateral, horizontal, and vertical jumping; and CoD tests, from which asymmetry indexes were calculated. The associations between asymmetry magnitudes were calculated with Spearman's ρ correlation coefficient. The agreement between the direction of asymmetries on different levels was calculated with Cohen's Kappa (κ) coefficient. The average magnitude of asymmetry varied substantially (2.9–40.3%). Most associations between asymmetry magnitudes measured on different levels were small and statistically non-significant, with a few exceptions of moderate and large associations. Asymmetry in single-leg countermovement jump parameters was strongly associated with hip abduction maximal strength ($\rho = 0.58$ and 0.50 , $p < 0.01$). Agreement between asymmetry directions was slight to fair, with a few moderate exceptions. Results indicate that multiple tests are needed to obtain a comprehensive picture of athletes' asymmetries and that universal thresholds and golden standard tests for return to play should be reconsidered and reinvestigated.

Keywords: asymmetry; hip and trunk; strength; range of motion; jumping; change of direction



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1. Introduction

Asymmetry, which refers to comparing the ability of one limb/side to another, has been a popular topic in recent sport science research [1]. It has been investigated for the purpose of finding its connection to sports injuries [2] or performance [3]. Various tests have been used to quantify asymmetry. Strength asymmetry has been tested with isokinetic dynamometry [4], unilateral and bilateral isometric mid-thigh pull [5], squat [6], jumping with unilateral and bilateral single-leg countermovement [7], drop [8] jump, and various horizontal jumps [9]. In addition, CoD has been used for testing asymmetry in specific sport movements; most commonly used has been the 505 test [10].

Just as with motor abilities, lateral asymmetry can be inspected on different levels: single-joint level, such as in knee flexion/extension [4]; complex movement level, such as in jumping [7]; and skill level, such as in CoD [10]. Although previous research showed a relationship between motor abilities measured on different levels [11,12], the existence of that kind of relationship between asymmetry levels is still an open question. Further complicating that relationship is the fact that asymmetry is a variable that includes two pieces of information: magnitude and direction [13]. Past research has been mostly concentrated on the asymmetry magnitude [14], while the direction of asymmetry has only recently been in focus [15].

Studies which considered the magnitude of asymmetry association found a significant correlation between single-joint asymmetries in isokinetic knee flexion strength and complex movement asymmetries in peak force during the bilateral squat ($r = 0.67, p < 0.05$), in countermovement jump height ($r = 0.79, p < 0.05$) [16], and in single-leg countermovement jump height ($r = 0.61, p < 0.05$) [17]. Both studies showed no association between complex movement asymmetries and asymmetries in knee extension strength. Contrary to those results was the study of Impellizzeri et al., which found an association between asymmetries in bilateral vertical jump peak force and isokinetic concentric knee extension ($r = 0.48, p < 0.01$), but not with leg flexion [18]. Conversely, factor analysis in Menzel et al.'s study showed that single-joint asymmetries in knee flexion/extension (peak torque and work) and complex movement asymmetries in bilateral countermovement jump (impulse, peak force, and power) were two different factors [4]. This inconsistency in results can be attributed to differences in isokinetic protocol (mainly speed), but not population, because excluding Newton et al.'s [16] research that was done on softball players, all other investigations were measuring high-level soccer players. Additionally, there is a methodological issue, considering that most researchers chose bilateral movement to quantify magnitudes in complex movement asymmetries.

Several studies investigated the association between magnitudes of complex movement and skill-level asymmetries. Most of them showed a lack of significant association between magnitudes of CoD asymmetries and complex movement asymmetries measured with bilateral squat [14], unilateral single-leg countermovement and drop jump [10,19], and unilateral isometric mid-thigh pull [20]. The exception is a study by Kozinc and Šarabon conducted on volleyball players, which found just one negative moderate association between single-leg lateral jump and CoD 90° ($r = -0.45, p < 0.05$) [21].

We can conclude that the evidence behind the association between asymmetry magnitudes measured on different levels is insufficient. Research that was investigating the association between asymmetry magnitudes reported conflicting results [17,18] and was mostly conducted on the soccer population [4,10,17–19], which does not give us a clear picture of asymmetry magnitude relationships in other sports. Several studies have methodological issues of using bilateral tests for asymmetry magnitude quantification [4,18]. Furthermore, single-joint asymmetry was only measured in maximal strength during knee movement [4,16,17], while explosive strength, range of motion, and hip and trunk as body parts were neglected.

Unlike asymmetry magnitudes, direction has only recently been a topic of scientific research. Most of the research that investigated agreement between the direction of asymmetries was focused on the same type of movement: jumping. On young handball players, it has been shown that asymmetries rarely favored the same side when measured with different jumping tests (unilateral, horizontal, and vertical jumps) (Kappa = -0.05 – 0.15) [22]. Contrary to that, a study of Bishop et al. [23], conducted on female soccer players, observed a substantial agreement between direction of asymmetry measured with the single-leg squat and countermovement jump (Kappa = 0.35 – 0.61), but slight to fair agreement when the same jumps were compared with single-leg drop jumps (Kappa = -0.26 – 0.26). These results indicate that asymmetry direction is mostly task-dependent, with few exceptions, when asymmetry is measured with various jumping tests.

Only a few studies have investigated agreement in asymmetry direction between different levels of asymmetry. Padros-Mainer et al. [24], with a study conducted on female soccer players, showed poor to fair levels of agreement (Kappa = -0.31 – 0.24) in asymmetry direction between jumps (horizontal and vertical) and change of direction. In accordance with this is the study by Kozinc and Šarabon, conducted on volleyball players, that also showed poor agreement (Kappa < 0.2) between complex movement asymmetries measured with single-leg horizontal and vertical jumps and asymmetries in CoD (90° and 180°) [21].

Asymmetry direction is a quite new topic in research. Some research shows substantial levels of agreement between asymmetry directions measured with different tests [23]. However, previous authors suggested that asymmetry rarely favors the same side between

tasks and that further investigation is needed to provide a clearer picture of the task-specific nature of asymmetries [13,21,24]. Although previous research suggests sport games which contain CoD and pivoting movement can develop sport asymmetries, the majority of asymmetry studies used a soccer population, and basketball as a sport was neglected [13].

Therefore, the aim of this study is to investigate the association of asymmetry magnitude and agreement in asymmetry direction between asymmetries on single-joint (hip and trunk), complex movement (horizontal and vertical jumps), and skill (CoD) levels. We hypothesize that there will be significant association and agreement between the levels of asymmetries.

2. Materials and Methods

2.1. Subjects

Seventeen senior and twenty-six junior elite basketball players (age: 20.5 ± 6.0 years; body mass: 86.8 ± 10.1 kg; height: 194.5 ± 7.2 cm). All participants volunteered to be part of the experiment and have signed informed consent, parents or guardians signed consents for underaged participants. Participants were highly trained athletes who were part of structured basketball within at least the last 6 months and with performance programs of 16–24 h/week. Inclusion criteria for this study were at least three years of experience in resistance training and no injuries during the last twelve months. This study was a part of the TELASI-PREVENT project (Slovenian Research Agency approval code: L5-1845), which has been carried out in accordance with the Declaration of Helsinki and the protocol was approved by the Slovenian National Medical Ethics Committee (identification code: 0120-99/2018/5). All subjects (their parents/guardians in case of underage) involved in the study signed the written informed consent.

2.2. Study Design, Tasks, and Procedures

This study has followed the design of an observational cross-sectional study. Complete data collection for this study has been conducted in basketball gyms during in-season national team break. Participants refrained from physical activity 24 h before start of testing. Whole testing session lasted approximately 150 min. It started with 15 min warm-up (low-intensity running, dynamic stretching, and bodyweight activation exercises). Data collection was conducted in four groups (randomized) that completed testing stations in random order (testing stations: jumping, CoD, hip and trunk dynamometry, hip and trunk range of motion). Rest between testing stations lasted for 5 min, after which participant would complete 3 practice trials before starting his testing trials. Best result out of three trials for each side/leg was taken for further analysis for all tests except range of motion (mean of three trials).

2.2.1. Jumping

Vertical jumping test (Single-leg countermovement jump (SLCMJ)) was conducted using force platform (Kistler, Switzerland). Participant was instructed to keep his hands on hips during complete test and non-testing leg slightly flexed (knee at $\sim 90^\circ$) without swinging it during jumping. Participant would perform countermovement until reaching depth of 90° knee flexion (visually instructed), after which he jumped as high as possible, landing on two feet and holding position for 2–3 s. Three alternated (left and right) trials were performed for each leg with 30 s rest in between each trial. If all mentioned instructions were followed, jump would be accepted, and highest peak force (N), peak power (W), and jump height (m) would be taken for analysis.

Horizontal jump tests (single-leg horizontal jump (SLHJ), single-leg lateral jump (SLLJ), and single-leg triple jump (SLTJ)) were performed on a flat surface (basketball court); detailed description of the procedures may be found elsewhere [25]. In brief, participant was directed to stand on one leg with tested leg toe (except the inner edge of feet for SLLJ) at starting line with his hands on hips. From that position, participant would jump (one horizontal jump for SLHJ, three jumps for SLTJ, and one lateral jump for

SLLJ) as far as possible and land on two feet. The distance was measured, with measuring tapes affixed to the ground, from starting line to heel (medial edge for SLLJ) of the leg closer to the starting line. Three alternated (left and right leg) trials were performed for each leg with 30 s rest in between each trial, and longest of three jumps for each leg was taken for analysis.

2.2.2. Hip and Trunk Strength

To calculate isometric lateral flexion trunk strength (peak torque (PT) (Nm/kg)), we used trunk dynamometer (S2P Ltd., Ljubljana, Slovenia), based on Markovic et al. [26] protocol. In brief, participant was standing (in training shoes) perpendicular to dynamometer with spine in neutral position, and position was fixed with rigid strap across the pelvis. Every trial was measured as maximal voluntary contraction held for 3–5 s, and highest in one second was taken for further analysis. Each side was measured three times (60 s rest between trials), and best result for each side was taken for analysis.

To calculate isometric hip strength (PT (Nm/kg)) and rate of torque development (RTD) (Nm/ms), we used a multipurpose dynamometer (Muscleboard, S2P d.o.o., Ljubljana, Slovenija) based on Marušić et al.'s [27] protocol. Flexion was measured unilaterally with participant in sitting position (knee fully extended and hip in 30° flexion) and non-tested leg on the ground. Extension was measured unilaterally with participant lying in prone position, with tested leg fully extended and non-tested leg resting in 90° knee flexion. Abduction/adduction was measured bilaterally with participant in sitting position (knee fully extended and hip in 30° flexion). Hip internal/external rotation was measured bilaterally with participant in four-point kneeling position (hips and knees in 90° flexion). During all measurements, except internal/external rotations, good fixation was ensured with rigid strap tightened across pelvis. One second interval of maximal voluntary contraction was executed to determine isometric strength, from which 100-ms of RTD was extracted (Δ torque/ Δ time value). Rest between trials was set for 60 s. Highest result out of three trials was taken for analysis.

2.2.3. Hip and Trunk Range of Motion

Participants passive hip RoM (°) was calculated with the help of digital inclinometer (Baseline, Fabrication Enterprises Inc., White Plains, NY, USA) and handheld goniometer (Baseline, Fabrication Enterprises Inc., White Plains, NY, USA). To minimize error, participants were marked with anatomic points specific to each test. To minimize subjectivity, examiner was assisted, which assured good fixation of instrument. Hip flexion and extension were measured with inclinometer, which was positioned to follow the line between femur trochanter major and lateral condyle of tested leg. Hip internal and external rotation were measured with inclinometer, which was positioned at center of tibia. Hip abduction and adduction were measured with a goniometer, fixed arm was pointed toward the other anterior superior iliac spine, and adjustable arm was pointed toward the tested leg patella. Hip flexion (Figure 1A) measurement started with participant lying in supine position with non-tested leg fully extended and fixated on the ground. Examiner would move tested leg into hip flexion, ensuring knee extension throughout whole movement, and end of motion was determined by the first pelvic movement (Figure 1B). Hip extension measurement started with participant lying in prone position with non-tested leg fully extended and fixated on the ground and tested leg in knee flexion (~90°). Examiner would move tested leg into hip extension, and end of motion was determined by the first pelvic movement. Hip internal and external rotation measurement started with participant lying in prone position with non-tested leg fully extended and fixated on the ground and tested leg in 90° knee flexion. Examiner would internally/externally rotate the leg ensuring 90° knee flexion, and end of motion was determined by the first pelvic movement. Hip abduction measurement started with participant in supine lying position with legs in neutral position, examiner would abduct the tested leg, end of motion was determined by the first pelvic movement. Hip adduction measurement started in supine lying position with tested leg in neutral

position and non-tested leg lying off the table in $\sim 30^\circ$ abduction. Each movement/leg was tested three times, and mean result was taken for analysis.



Figure 1. Position of participant during hip flexion range-of-motion testing. (A) start; (B) finish.

Trunk lateral RoM (m) (Figure 2) was calculated with the help of measuring tape as the distance between the starting and end positions of the middle finger of tested side in relation to the floor. Starting position was set as the participant standing with the back to the wall, barefoot and feet apart at the hip-width (Figure 2A). End RoM was set after the participant would perform maximal lateral flexion by sliding down without losing contact to the wall or lifting any part of his feet off the ground (Figure 2B). Each side was measured three times, and mean result was taken for analysis.



Figure 2. Position of participant during trunk lateral flexion range-of-motion testing. (A) start; (B) finish.

2.2.4. Change of Direction

CoD was measured with three tests/angles, characterized by turning angles (90° , 135° and 180°), as outlined by Rouissi et al. [28]. We used photocells (Brower Timing Systems; Draper, UT, USA) to ensure accurate time. Tests started with participant standing 0.3 m from the starting line, on which photocells were positioned. All the tests were 10 m long, consisting of 5 m of sprint; change of direction of 90° , 135° , and 180° ; and 5 m of sprint to the finish line (where photocells were positioned). Participant was instructed to change direction over marker set on the ground, which they had to step on in every trial. All tests were done three times with each leg, which was alternated in every trial. Rest between every repetition was set for one minute. The CoD would be accepted if all the above-mentioned instructions were followed. Otherwise, the trial would be repeated after one-minute rest. The best trial for each leg was taken for further analysis.

2.3. Statistical Analyses

Statistical analyses were performed with help from SPSS Statistical Software (Version 20, IBM, Armonk, NY, USA) package. All data are presented as means and their standard deviations. The coefficient of variation (CV) and intra-class coefficient correlation (ICC) model 2,1 (two-way random effects, absolute agreement, single rater/measurement) for each task and side were determined to evaluate reliability [29]. Reliability results were interpreted according to Koo and Li [30].

Lateral asymmetry was calculated with the following equation [31]:

$$\text{Asymmetry (\%)} = ((\max(\text{left or right}) - \min(\text{left or right})) / (\max(\text{left or right})) \times 100$$

Cohen's Kappa (κ) coefficient was used for calculation agreement between the direction of asymmetries, and it was performed with custom-made MatLab script [32] in MatLab software package (Version R2018a, Mathworks, USA). Level of agreement was interpreted as slight ($\kappa = 0.0\text{--}0.20$), fair ($\kappa = 0.21\text{--}0.40$), moderate ($\kappa = 0.41\text{--}0.60$), substantial ($\kappa = 0.61\text{--}0.80$), or almost perfect ($\kappa \geq 0.81$) [33].

Shapiro-Wilk's tests were performed to assess the normality of distribution of asymmetry variables; only 5 out of 20 variables (all of which were part of the single-joint asymmetries group) were normally distributed given the alpha level of 0.05. Therefore, the association between magnitudes of different levels of asymmetries was calculated with Spearman's ρ correlation coefficient. The correlation was interpreted as trivial ($\rho < 0.1$), small ($\rho = 0.1\text{--}0.3$), moderate ($\rho = 0.3\text{--}0.5$), large ($\rho = 0.5\text{--}0.7$), very large ($\rho = 0.7\text{--}0.9$), or extremely large ($\rho > 0.9$) [34]. The threshold for statistical significance was set to $\alpha < 0.05$.

3. Results

The summary of all outcome measures, including mean asymmetry indexes for all tests and reliability, is presented in Table 1. The majority of the tests showed excellent reliability either through CV or ICC evaluation. Hip explosive strength parameter, RTD, showed only moderate reliability. Additionally, RoM in trunk lateral flexion and hip adduction showed moderate reliability estimated with ICC, but excellent estimated with CV.

CoD asymmetries showed the smallest mean values (2.9–3.8%). Asymmetries in different horizontal jumping showed mean values up to 5% (3.5–4.8%). Alternatively, asymmetries in vertical jumping were more sensitive and therefore expressed a larger magnitude of asymmetry (mean values of various parameters: 4.8–11.1%). Next, asymmetries in hip and trunk RoM (5.9–13.5%) and strength (PT) (3.8–12.8%) showed a similar range of mean values. Asymmetry in hip explosive strength (RTD) showed the largest range of mean values (10.7–40.3%).

Associations between single-joint and complex movement asymmetry magnitudes and Kappa values of agreement between asymmetry directions are summarized in Table 2. Most correlation coefficients were trivial to small and statistically non-significant. With some exceptions, large correlations were found only between asymmetry in hip abduction PT, asymmetry in height ($\rho = 0.58$, $p < 0.01$), and peak power ($\rho = 0.50$, $p < 0.01$) during SLCMJ. Asymmetry in various parameters of SLCMJ showed moderate correlation with asymmetries in hip adduction ($\rho = 0.31$, $p < 0.05$) and flexion ($\rho = -0.31$ and -0.38 , $p < 0.05$) PT, trunk lateral flexion ($\rho = 0.3$, $p < 0.05$) PT, and hip flexion ($\rho = 0.36$ and 0.41 , $p < 0.05$) RoM. The only horizontal jumping asymmetry that had a significant correlation was SLTJ, which correlated with asymmetry in hip flexion RTD ($\rho = -0.37$, $p < 0.05$) and RoM ($\rho = 0.43$, $p < 0.01$). The agreement between outcome measures was generally slight to fair (mostly $\kappa < 0.3$) and statistically non-significant, except for the agreements between hip internal rotation PT, SLHJ ($\kappa = 0.41$, $p < 0.05$, only moderate agreement), and SLLJ ($\kappa = 0.30$, $p < 0.05$); between hip external rotation RTD and SLHJ ($\kappa = 0.33$, $p < 0.05$); between hip flexion PT and SLCMJ height ($\kappa = 0.32$, $p < 0.05$); and between hip external rotation RoM and SLTJ ($\kappa = 0.32$, $p < 0.05$).

Table 1. Summary of all outcome measures for both limbs and asymmetry indexes.

Outcome Measure/Task	(Mean $\pm$ SD)	CV (%) (CI 95%)	ICC (CI 95%)	(Mean $\pm$ SD)	CV (%) (CI 95%)	ICC (CI 95%)	Asymmetry Index (%)
	Left			Right			
SLCMJ _H (m)	0.17 $\pm$ 0.04	13.0 (12.1–14)	0.84 (0.74–0.92)	0.17 $\pm$ 0.04	16.9 (15.1–18.8)	0.82 (0.74–0.90)	11.1 $\pm$ 8.3
SLCMJ _F (N/kg)	212.57 $\pm$ 17.31	3.9 (3.7–4.2)	0.93 (0.90–0.96)	210.32 $\pm$ 16.97	3.8 (3.6–4)	0.95 (0.92–0.98)	4.8 $\pm$ 4.4
SLCMJ _P (W/kg)	33.31 $\pm$ 4.71	7.5 (7–8.1)	0.98 (0.97–0.99)	33.43 $\pm$ 5.11	8 (7.3–8.6)	0.99 (0.99–1.00)	7.1 $\pm$ 6.8
SLHJ (m)	183.65 $\pm$ 18.12	4.6 (4.2–4.9)	0.96 (0.94–0.98)	181.55 $\pm$ 15.50	4.3 (4.1–4.5)	0.96 (0.95–0.98)	4.6 $\pm$ 3.2
SLLJ (m)	174.07 $\pm$ 19.74	5.1 (4.8–5.3)	0.94 (0.90–0.98)	167.81 $\pm$ 18.09	3.7 (3.4–3.9)	0.96 (0.92–0.98)	4.8 $\pm$ 3.7
SLTJ (m)	580.56 $\pm$ 52	3.3 (3.1–3.5)	0.95 (0.92–0.97)	575.53 $\pm$ 49.47	3.6 (3.4–3.8)	0.95 (0.91–0.97)	3.5 $\pm$ 2.7
CoD _{90°} (s)	2.26 $\pm$ 0.13	2.4 (2.3–2.6)	0.91 (0.88–0.93)	2.27 $\pm$ 0.15	2.9 (2.7–3)	0.91 (0.88–0.94)	3.8 $\pm$ 2.6
CoD _{135°} (s)	2.53 $\pm$ 0.12	3 (2.8–3.1)	0.87 (0.82–0.92)	2.49 $\pm$ 0.16	2.7 (2.6–2.9)	0.90 (0.86–0.94)	2.9 $\pm$ 3.2
CoD _{180°} (s)	2.67 $\pm$ 0.15	2.6 (2.4–2.7)	0.91 (0.88–0.94)	2.64 $\pm$ 0.15	2.9 (2.7–3.1)	0.92 (0.88–0.96)	3.0 $\pm$ 2.9
Hip ABD _{PT} (Nm/kg)	2.13 $\pm$ 0.31	4.5 (4.2–4.8)	0.97 (0.96–0.98)	2.15 $\pm$ 0.33	4.4 (4.1–4.7)	0.95 (0.93–0.97)	3.7 $\pm$ 3.1
Hip ABD _{RTD100} (%MVC/s)	621.29 $\pm$ 266.09	51.6 (48.9–54.2)	0.61 (0.51–0.69)	633.2 $\pm$ 279.6	49.7 (46.9–52.4)	0.66 (0.59–0.72)	11.2 $\pm$ 9.7
Hip ADD _{PT} (Nm/kg)	2.04 $\pm$ 0.45	4.4 (4.1–4.7)	0.94 (0.93–0.96)	2.06 $\pm$ 0.45	4.6 (4.4–4.9)	0.95 (0.93–0.96)	5.6 $\pm$ 4.8
Hip ADD _{RTD100} (%MVC/s)	559.68 $\pm$ 324.03	47 (44.6–49.5)	0.62 (0.53–0.70)	608.26 $\pm$ 344.69	47.5 (45.1–49.8)	0.69 (0.59–0.79)	10.7 $\pm$ 10.3
Hip EXROT _{PT} (Nm/kg)	0.92 $\pm$ 0.29	6.2 (5.8–6.5)	0.96 (0.95–0.97)	0.94 $\pm$ 0.31	6.3 (5.9–6.8)	0.93 (0.92–0.94)	7.9 $\pm$ 5.8
Hip EXROT _{RTD100} (%MVC/s)	266.01 $\pm$ 140.77	39.2 (37.1–41.3)	0.71 (0.64–0.77)	264 $\pm$ 137.53	40.6 (38.4–42.8)	0.75 (0.65–0.85)	13.2 $\pm$ 8.8
Hip INROT _{PT} (Nm/kg)	1.04 $\pm$ 0.41	5.8 (5.5–6.2)	0.94 (0.92–0.95)	1.11 $\pm$ 0.41	5.2 (4.9–5.6)	0.94 (0.92–0.95)	11.5 $\pm$ 7.2
Hip INROT _{RTD100} (%MVC/s)	284.21 $\pm$ 176.43	41.6 (39.5–43.6)	0.61 (0.52–0.69)	293.65 $\pm$ 188.44	40.7 (38.7–42.7)	0.58 (0.52–0.63)	13.2 $\pm$ 9.6
Hip EXT _{PT} (Nm/kg)	2.69 $\pm$ 0.83	5.9 (5.5–6.3)	0.94 (0.93–0.96)	2.78 $\pm$ 0.71	6.6 (6–7.2)	0.91 (0.88–0.95)	11.0 $\pm$ 8.9
Hip EXT _{RTD100} (%MVC/s)	708.18 $\pm$ 455.34	52 (49.1–54.9)	0.65 (0.56–0.72)	659.87 $\pm$ 486.29	46.7 (44.7–48.6)	0.63 (0.58–0.68)	30.6 $\pm$ 21.8
Hip FLEX _{PT} (Nm/kg)	2.04 $\pm$ 0.41	5.7 (5.3–6)	0.95 (0.93–0.96)	2.14 $\pm$ 0.38	4.7 (4.5–5)	0.92 (0.90–0.94)	9.9 $\pm$ 8.4
Hip FLEX _{RTD100} (%MVC/s)	585.04 $\pm$ 327.21	53.5 (50.6–56.4)	0.76 (0.69–0.82)	562.74 $\pm$ 414.39	51.7 (49.6–53.8)	0.79 (0.73–0.85)	40.3 $\pm$ 20.4
Trunk LATFLEX _{PT} (Nm/kg)	3.47 $\pm$ 1.17	9.2 (8.6–9.8)	0.97 (0.96–0.98)	3.58 $\pm$ 1.1	9.5 (8.9–10.1)	0.93 (0.90–0.96)	12.8 $\pm$ 9.6
Trunk LATFLEX _{ROM} (cm)	24.13 $\pm$ 3.04	3.1 (2.8–3.4)	0.61 (0.51–0.69)	24.03 $\pm$ 3.28	3.1 (2.9–3.4)	0.67 (0.59–0.75)	9.0 $\pm$ 5.9
Hip ABD _{ROM} (°)	45.46 $\pm$ 6.17	5 (4.7–5.2)	0.85 (0.75–0.92)	43.48 $\pm$ 6.43	4.4 (4.1–4.6)	0.89 (0.84–0.93)	8.9 $\pm$ 5.7
Hip ADD _{ROM} (°)	26.3 $\pm$ 4.38	7.2 (6.8–7.5)	0.81 (0.70–0.91)	27.93 $\pm$ 3.92	7.3 (6.9–7.7)	0.77 (0.65–0.88)	8.8 $\pm$ 6.7
Hip FLEX _{ROM} (°)	105.61 $\pm$ 15.7	2.8 (2.6–2.9)	0.96 (0.93–0.98)	103.43 $\pm$ 16.29	2.5 (2.4–2.6)	0.96 (0.94–0.98)	5.9 $\pm$ 6.2
Hip EXT _{ROM} (°)	25.91 $\pm$ 5.21	6.9 (6.5–7.2)	0.93 (0.88–0.95)	25.64 $\pm$ 6.22	7.8 (7.3–8.3)	0.94 (0.89–0.97)	12.8 $\pm$ 11.0
Hip EXROT _{ROM} (°)	49.2 $\pm$ 7.88	4.3 (4.1–4.4)	0.92 (0.86–0.95)	47.58 $\pm$ 8.77	3.9 (3.7–4.1)	0.95 (0.91–0.97)	11.2 $\pm$ 7.3
Hip INROT _{ROM} (°)	41.59 $\pm$ 7.33	4.5 (4.2–5.2)	0.92 (0.88–0.95)	42.22 $\pm$ 7.78	6.2 (5.6–6.8)	0.89 (0.76–0.95)	13.5 $\pm$ 10.6

SLHJ—single-leg horizontal jump, SLTJ—single-leg triple jump, SLLJ—single-leg lateral jump, SLCMJ—single-leg countermovement jump, H—height, F—peak force, P—peak power, CoD—Change of direction, RTD—rate of torque development, ROM—range of motion, ADD—adduction, ABD—abduction, EXT—extension, FLEX—flexion, EXROT—external rotation, INROT—internal rotation, LATFLEX—lateral flexion.

Table 2. Spearman's correlation and Cohen's Kappa coefficients between single-joint and complex movement asymmetries.

Asymmetry		SLHJ	SLLJ	SLTJ	SLCMJ _H	SLCMJ _F	SLCMJ _P
Trunk LATFLEX _{PT}	ρ	−0.14	−0.28	0.06	0.04	0.02	0.31 *
	κ	−0.01	0.13	0.17	0.13	−0.03	0.05
Hip ABD _{PT}	ρ	0.09	0.19	0.21	0.58 **	0.17	0.50 **
	κ	0.05	0.05	0.05	0.19	0.05	0.10
Hip ABD _{RTD100}	ρ	0.24	0.13	0.14	0.30	0.22	0.20
	κ	0.09	0.07	−0.01	0.14	0.28	0.05
Hip ADD _{PT}	ρ	0.31 *	−0.14	−0.07	0.27	0.30	0.14
	κ	0.16	−0.05	0.17	0.27	0.17	0.10
Hip ADD _{RTD100}	ρ	0.17	−0.12	0.28	−0.19	0.06	−0.03
	κ	0.00	−0.23	0.06	0.03	0.13	0.12
Hip EXROT _{PT}	ρ	0.09	−0.24	0.08	0.24	0.21	0.20
	κ	0.03	0.06	0.11	0.21	0.01	0.09
Hip EXROT _{RTD100}	ρ	0.07	−0.07	−0.07	0.09	0.15	0.24
	κ	0.33 *	0.10	0.13	0.11	0.13	0.19
Hip INROT _{PT}	ρ	0.16	−0.01	0.13	0.23	0.11	0.13
	κ	0.41 *	0.30 *	0.08	0.24	0.28	0.08
Hip INROT _{RTD100}	ρ	0.05	−0.09	0.03	−0.16	−0.20	0.01
	κ	0.10	0.02	0.10	0.04	0.09	0.24
Hip EXT _{PT}	ρ	−0.10	−0.06	−0.15	0.01	0.09	0.07
	κ	0.17	0.19	0.20	0.24	−0.03	0.11
Hip EXT _{RTD100}	ρ	−0.03	−0.27	−0.09	0.02	0.19	0.27
	κ	0.22	0.06	0.11	−0.03	0.17	0.01
Hip FLEX _{PT}	ρ	0.06	−0.06	0.25	−0.27	−0.38 *	−0.31 *
	κ	−0.01	0.15	−0.03	0.32 *	0.17	0.04
Hip FLEX _{RTD100}	ρ	−0.22	−0.15	−0.37 *	−0.08	−0.22	−0.04
	κ	0.15	0.18	0.03	−0.01	0.22	0.00
Hip ABD _{ROM}	ρ	−0.18	−0.06	0.03	−0.18	−0.04	−0.12
	κ	0.21	0.10	0.13	0.11	0.13	0.15
Hip ADD _{ROM}	ρ	0.08	0.15	−0.03	−0.11	−0.19	−0.18
	κ	0.23	−0.21	0.18	−0.03	−0.11	0.02
Hip EXROT _{ROM}	ρ	−0.03	0.05	−0.01	0.26	−0.01	0.00
	κ	0.16	−0.08	0.34 *	0.20	0.15	0.16
Hip INROT _{ROM}	ρ	0.08	0.19	0.12	−0.02	−0.14	−0.28
	κ	0.35 *	0.13	0.01	0.12	0.21	0.18
Hip EXT _{ROM}	ρ	0.17	0.00	−0.08	0.03	−0.05	0.12
	κ	0.14	0.14	0.14	0.19	0.24	0.29
Hip FLEX _{ROM}	ρ	0.15	0.05	0.43 **	0.37 *	0.24	0.41 **
	κ	0.06	0.10	0.03	0.11	0.13	0.09
Trunk LATFLEX _{ROM}	ρ	0.06	−0.06	0.01	0.17	0.04	0.07
	κ	0.11	0.13	0.12	0.07	0.17	0.04

SLHJ—single-leg horizontal jump, SLTJ—single-leg triple jump, SLLJ—single-leg lateral jump, SLCMJ—single-leg countermovement jump, H—height, F—peak force, P—peak power, RTD—rate of torque development, ROM—range of motion, ADD—adduction, ABD—abduction, EXT—extension, FLEX—flexion, EXROT—external rotation, INROT—internal rotation, LATFLEX—lateral flexion. * $p < 0.05$, ** $p < 0.01$.

Associations between single-joint and skill-level asymmetry magnitudes and Kappa values of agreement between asymmetry directions are summarized in Table 3. Most correlation coefficients were trivial to small and statistically non-significant. Only a few exceptions were observed: the associations between asymmetries in CoD 90°, hip abduction RoM ($\rho = -0.48$, $p < 0.01$), and hip extension RTD ($\rho = -0.37$, $p < 0.05$); and CoD 135°, hip flexion PT ($\rho = -0.37$, $p < 0.05$), and RoM ($\rho = 0.39$, $p < 0.05$). The agreement between outcome measures was generally slight to fair (most $\kappa < 0.3$) and statistically non-significant, except for the agreements between CoD 90° and trunk lateral flexion PT ($\kappa = 0.34$, $p < 0.05$), CoD 135° and hip flexion RTD ($\kappa = 0.33$, $p < 0.05$), and CoD 180° and hip flexion PT ($\kappa = 0.33$, $p < 0.05$).

Table 3. Spearman’s correlation and Cohen’s Kappa coefficients between single-joint asymmetries and asymmetries in change of direction.

Asymmetry		CoD _{90°}	CoD _{135°}	CoD _{180°}
Trunk LATFLEX _{PT}	ρ	−0.08	0.12	−0.03
	κ	0.34 *	0.00	0.05
Hip ABD _{PT}	ρ	−0.05	0.29	−0.01
	κ	0.00	0.24	0.10
Hip ABD _{RTD100}	ρ	−0.12	0.19	0.02
	κ	0.05	0.10	0.14
Hip ADD _{PT}	ρ	0.03	0.07	−0.14
	κ	0.01	0.05	0.01
Hip ADD _{RTD100}	ρ	0.18	0.08	0.05
	κ	0.17	0.24	0.17
Hip EXROT _{PT}	ρ	−0.03	−0.13	0.08
	κ	0.01	0.05	0.01
Hip EXROT _{RTD100}	ρ	0.15	0.02	−0.05
	κ	0.19	0.24	0.09
Hip INROT _{PT}	ρ	0.06	−0.19	0.10
	κ	0.08	0.05	0.02
Hip INROT _{RTD100}	ρ	0.06	0.04	0.04
	κ	0.05	0.19	0.14
Hip EXT _{PT}	ρ	−0.14	−0.16	−0.08
	κ	0.08	0.14	0.11
Hip EXT _{RTD100}	ρ	−0.37 *	0.10	−0.13
	κ	−0.01	0.24	0.09
Hip FLEX _{PT}	ρ	−0.08	−0.37 *	0.15
	κ	0.15	0.00	0.33*
Hip FLEX _{RTD100}	ρ	−0.14	−0.12	−0.07
	κ	0.00	0.33 *	0.19
Hip ABD _{ROM}	ρ	−0.48 **	−0.04	0.12
	κ	0.04	0.10	0.06
Hip ADD _{ROM}	ρ	0.05	0.02	−0.05
	κ	0.12	0.10	0.12
Hip EXROT _{ROM}	ρ	0.13	0.04	−0.01
	κ	0.06	0.00	0.13
Hip INROT _{ROM}	ρ	0.16	0.12	0.01
	κ	0.01	0.24	0.28
Hip EXT _{ROM}	ρ	0.06	−0.12	0.13
	κ	0.19	0.05	0.10
Hip FLEX _{ROM}	ρ	0.09	0.39 *	0.12
	κ	0.10	0.05	0.28
Trunk LATFLEX _{ROM}	ρ	0.02	0.23	−0.05
	κ	0.14	0.10	0.23

CoD—Change of direction, RTD—rate of torque development, ROM—range of motion, ADD—adduction, ABD—abduction, EXT—extension, FLEX—flexion, EXROT—external rotation, INROT—internal rotation, LATFLEX—lateral flexion. * $p < 0.05$, ** $p < 0.01$.

Associations between complex movement and skill-level asymmetry magnitudes and Kappa values of agreement between asymmetry directions are summarized in Table 4. Most correlation coefficients were trivial to small and statistically non-significant. Only a few exceptions were detected: the associations between asymmetries in CoD 135° and peak force during SLCMJ ($\rho = 0.34$, $p < 0.05$) and CoD 180° and length of SLTJ ($\rho = 0.38$, $p < 0.05$). The agreement between outcome measures was generally slight to fair (most $\kappa < 0.3$) and statistically non-significant, except for agreements between peak power during SLCMJ and CoD 90° ($\kappa = 0.33$, $p < 0.05$) and 135° ($\kappa = 0.38$, $p < 0.05$).

Table 4. Spearman's correlation and Cohen's Kappa coefficients between complex movement asymmetry and asymmetries in change of direction.

Asymmetry		CoD _{90°}	CoD _{135°}	CoD _{180°}
SLHJ	ρ	0.12	0.03	−0.07
	κ	0.00	0.05	0.19
SLLJ	ρ	0.29	0.04	0.14
	κ	0.17	0.05	−0.02
SLTJ	ρ	0.10	0.18	0.38 *
	κ	0.20	0.05	−0.01
SLCMJ _H	ρ	−0.09	0.12	0.01
	κ	0.24	0.29	0.05
SLCMJ _F	ρ	−0.18	0.34 *	0.19
	κ	0.28	0.14	−0.01
SLCMJ _P	ρ	−0.28	0.26	0.03
	κ	0.33 *	0.38 *	0.14

SLHJ—Single-leg horizontal jump, SLTJ—Single-leg triple jump, SLLJ—Single-leg lateral jump, SLCMJ—Single-leg countermovement jump, H—height, F—peak force, P—peak power, CoD—Change of direction. * $p < 0.05$.

4. Discussion

The aim of the present study was to establish the association and agreement between asymmetries measured on single-joint (hip and trunk), complex movement (horizontal and vertical jumps) and skill (CoD) level. The findings showed a rare significant, mostly moderate, association between asymmetry magnitudes measured on different levels. In addition, asymmetry direction agreement was occasional and generally fair. From this, we cannot accept our hypothesis and can confirm the independent nature of asymmetry regardless of the level inspected or test used or whether the magnitude or direction of asymmetry are examined.

Most tests show exceptional reliability ($<10\%$ CV and ICC >0.90), suggesting that most of our data can be interpreted with confidence. We must point out that our hip RTD parameter shows only moderate reliability. Since RTD is a highly variable parameter we find that acceptable, but it should be interpreted with caution. Next, RoM in trunk lateral flexion and hip adduction showed excellent reliability measured with CV but moderate measured with ICC, but because we have taken average between three trials for all RoM tests, we find that acceptable. Generally, our mean asymmetry values are in accordance with previous studies, especially jumping and CoD tests [19,21]. Next, mean asymmetry scores in horizontal jumps were $<5\%$ (3.5–4.8%), which shows similar sensitivity to detect asymmetry values as CoD (2.9–3.8%). From a rehabilitation and return to play perspective, testing asymmetry with horizontal jumps has previously been widely practiced [35]. This and previous studies show that the horizontal jumping test shows similar sensitivity to the CoD test when it comes to asymmetry [24]. From that viewpoint, CoD is a more sport specific movement, especially for team sports, which makes it a suitable return to play test, same as horizontal jumps.

Previous studies have shown the existence of association between single-joint knee strength and jumping asymmetries [16–18], but because of the different body part (knee) and some methodological differences (bilateral test) direct comparison cannot be made. Although our results showed that most correlations between single-joint and complex movement asymmetries were non-significant, there were a few moderate to large associations (Table 2). The large association between hip abduction maximal isometric strength and SLCMJ parameters can be explained with medial gluteus activation during loading phase in single-leg vertical jumping [36]. The moderate association between hip flexion RoM and various jumping tests (SLCMJ and SLTJ) could be attributed to hip range of motion for SLTJ, which is required during the swing phase during jumps. Other significant associations between single-joint and complex movement asymmetries were small or negative, which we cannot explain.

To our knowledge, no previous studies investigated the association between single-joint and skill-level asymmetries, such as CoD, so direct comparison is not possible. Our result showed a few significant moderate associations (Table 3). The largest association was found between asymmetries in CoD 90° and hip abductions RoM. This relationship could be explained with the requirement of hip abduction range on motion during stance phase in CoD [12]. Next, another significant association was moderate, between asymmetry in hip flexion RoM and CoD 135°, which can be attributed to the necessity of hip flexion range of motion during push off into a new direction [28].

Our study showed a few moderate associations between jumping asymmetries (SLTJ and SLCMJ) and asymmetries in CoD (135° and 180°) (Table 4). These results are in contrast with previous research that found no association between asymmetries quantified with various vertical jumping tests and CoD 90° [10,19]. This can be attributed to different populations (soccer players) and jumping tests (drop jump). Next, different CoD angles were associated with various single-joint and complex movement asymmetries which can be attributed to the unique requirements and movement strategies of each CoD angle [37].

We used the Kappa coefficient to measure the agreement in asymmetry favoring the same side between different tests (Tables 2–4). Results showed mostly fair agreement, with one exception of moderate agreement, between SLHJ and hip internal rotation strength. Kappa coefficients between single-joint (hip and trunk) and complex movement (jumping) asymmetry directions were rarely significant, and generally under 0.3, which is in accordance with previous studies that measured single-joint strength asymmetries on knee joint [21]. Similarly, the agreement between asymmetries in CoD and single-joint and complex movement asymmetries was also generally non-significant, with a few cases of significant but only fair levels of agreement. These results are in accordance with a previous study that measured agreement between jumping and CoD asymmetry directions in female soccer players [24]. In addition, Bishop et al. [23] proved there is a substantial level of agreement (Kappa = 0.61) between squat jump and CMJ in female soccer players. From this, we can conclude the existence of agreement in asymmetry direction between tests, but not between levels, which provides further evidence of the individual nature of asymmetry.

A wide range of mean asymmetry magnitudes in different tasks and parameters, from mean 2.9% for CoD up to 40.3% for RTD, with the generally non-significant association and agreement between asymmetries measured on different levels, suggests an independent nature of asymmetries. This finding is in accordance with previous research that used various populations, tests, and body parts to quantify asymmetries [19,21,24,38], but no study used elite basketball players, which proves that relationships between asymmetries are not dependent on sport, test, parameters, or level of athletes. That implies that for a more holistic view of body asymmetry, a wide spectrum of tests should be part of the testing battery. Our results have important practical implications. Previous research set a threshold of 10% asymmetry that influences sport performance [3]. Taking that into consideration, we would advise physical coaches to examine athletes' asymmetries with tests that are close to sport-specific movements (like COD or jumping) of their sport, and to inspect asymmetries in single-joint movement that are determinants of those sport-specific tests. This approach would give a wide but specific picture of athletes' asymmetries, which would show a path that would help coaches in improving athletes' performance.

Limitations and Prospective

There are a few limitations that should be acknowledged. We must point out that our testing battery was large, with procedures taking up to 150 min. However, that kind of testing battery could lead to fatigue, which would influence results. Specificity of basketball game and training history, randomized testing procedures, and long testing pauses minimized the burden. Further, CoD asymmetry magnitudes were low, and we suggest future research to use CoD deficit as a more sensitive measure of asymmetry on skill level. Reliability of hip RTD was modest, but we find this acceptable, as RTD is a highly

variable parameter. In addition, some ROM parameters showed only moderate ICC values, which does point to the fact that some asymmetry relationship results should be taken with caution. Next, because our sample was selected from elite basketball players who have been under strict over-selection of physical, skill, and behavioral criteria over time, our sample is homogenous, so conclusions of this study are limited to high-level basketball population. Furthermore, this study has inspected relationships between asymmetries only on a univariate level. Therefore, taking that into consideration, we encourage future studies to use a wide testing battery on a larger heterogenous sample of the athlete population, so that relationships between asymmetries could be inspected on a multivariate level using principal component analysis.

5. Conclusions

This study investigated agreement in asymmetry direction and association in asymmetry magnitudes between asymmetries measured on different levels. Previous studies on various populations showed rare and low agreement between asymmetry directions measured using different tests, which is in accordance with our results. Next, the associations between asymmetry magnitudes were also rarely significant, but there were some pairs of large association, which opens the further question of whether asymmetry on skill level could be explained with multiple asymmetries on a single-joint and complex movement level. These findings suggest that one test is not enough to provide a clear picture of asymmetry testing and that a wide battery of tests should be included, especially on a single-joint level. Furthermore, that lack of relationship between asymmetries is not dependent on sport, test, parameters, or level of athlete.

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