Inter-limb Asymmetries:
The Need for an Individual Approach to Data Analysis

ABSTRACT

It has been shown that the magnitude of inter-limb asymmetries varies depending on the test selected; however, literature relating to whether asymmetries always favour the same limb is scarce. The aim of the present study was to determine whether inter-limb asymmetries always favoured the same side for common metrics across unilateral strength and jumping-based tests. Twenty-eight recreational sport athletes performed unilateral isometric squats, single leg countermovement jumps (SLCMJ) and single leg broad jumps (SLBJ) with asymmetries in peak force compared across all tests, and eccentric and concentric impulse asymmetries compared between jumps. Mean asymmetries for all tests were low (≤ -5.3%) and all inter-limb differences for jump tests favoured the left limb, whilst asymmetries during the isometric squat favoured the right limb. Despite the low mean asymmetry values, individual data highlighted substantially greater differences. Levels of agreement for asymmetries were computed via the Kappa coefficient and ranged from slight to substantial (< 0.01 – 0.79), although concentric impulse asymmetries for jump tests was the only comparison to result in substantial levels of agreement. With asymmetries rarely being present on the same side across tests, these results show that a more individual approach to reporting asymmetries is required, which should help practitioners when designing targeted training interventions for their reduction.

Key Words: Agreement, between-limb differences, individual monitoring, symmetry

INTRODUCTION

Inter-limb asymmetries refers to the concept of the performance of two limbs not being equal (3,21) and have been a popular source of investigation in recent years. Historically, many studies have highlighted the prevalence of inter-limb asymmetry across a range of tests such as the back squat (1,24,33), isometric squats or mid-thigh pulls (10,14,15), and jumping-based tasks (2,20,28,31). Although interesting, their prevalence alone does little to enhance our understanding of whether these differences should be corrected during training. More recently, studies have aimed to investigate whether such asymmetries are detrimental to physical or sports performance (6) with equivocal findings. For example, Hart et al. (15) showed that asymmetries in strength of ~8% were associated with reduced kicking accuracy, whilst Dos'Santos et al. (10) reported no association between strength asymmetries (~13%) and performance during the 505 change of direction speed test. Similarly, Dos'Santos et al. (11) reported no association between single and triple leg hop asymmetries and change of direction speed (CODS) performance, although it should be noted that the reported inter-limb differences of ~7% can be considered small (6). In contrast, Bishop et al. (4) showed that both vertical and horizontal asymmetries were associated with reduced jump (r = -0.47 to -0.56) and sprint (r = 0.49 to 0.59) performance in elite youth female soccer players. Consequently, this lack of agreement highlights the need for further research.

The majority of literature relating asymmetries to physical performance measures have used jump tests to quantify the asymmetry component (4,11,18,26,27). Inter-limb differences from horizontal jumping (such as single, triple, and crossover hop tests) have reported asymmetries of 6-7% (4,11,30). When vertical asymmetries have been assessed via a single leg countermovement jump (SLCMJ), these differences have been shown to be significantly greater than horizontal tests (4,26,29), with values > 10% common for this test. Finally, the use of drop jumps has highlighted individual asymmetry values > 50% (28) in healthy adult populations; thus, the available body of evidence would suggest that the magnitude of asymmetries are test-specific.

In addition to this varying magnitude, recent studies have displayed individual athlete asymmetry data highlighting that both the left and right (4,27) or dominant and non-dominant limbs (11,13) have the potential to score higher during jump testing. Despite these recent findings, to the authors' knowledge, no studies to date have used this approach to specifically examine if the levels of agreement in asymmetry (right versus left) is consistent across multiple tests. For example, if peak force (PF) data was obtained during two different types of unilateral jumps, such as a SLCMJ and single leg broad jump (SLBJ); would the same limb always record the larger peak force value despite the tests being different. Therefore, the aim of the present study was to assess if inter-limb asymmetries consistently occurred on the same limb during unilateral strength and power tests. When reporting inter-limb differences, it was hypothesised that both the magnitude and side which favoured the asymmetry would be test and metric-specific, and highly individual in nature, justifying the need for an individual approach to data analysis.

METHODS

Experimental Approach to the Problem

The present study required subjects to partake in two sessions. The first visit was for test familiarisation. Subjects were provided with the relevant test instructions and the opportunity to practice each assessment until they reached a satisfactory level of technical competence during each test (established by an accredited strength and conditioning coach). Data collection took place on the second visit. Subjects performed three trials on each limb for the following tests: unilateral isometric squats, SLCMJ and SLBJ on a single force platform (PASPORT force plate, PASCO Scientific, California, USA) sampling at 1000 Hz. Test order was randomized so as to negate any potential learning effects.

Subjects

Twenty-eight recreational sport athletes (age = 27.29 ± 4.6 years; mass = 80.72 ± 9.26 kg; height = 1.81 ± 0.06 m) volunteered to take part in this study. A minimum of 27 participants was determined from a priori power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) implementing statistical power of 0.8 and a type 1 alpha level of 0.05 which has been used in comparable literature (10). Inclusion criteria required all participants to have a minimum of one year of resistance training experience. In addition, participants were excluded from the study if they had a history of lower body injury or were injured at the time of testing. Participants were required to complete informed consent forms to demonstrate that they were willing and able to undertake all testing protocols. Ethical approval was granted from the Research and Ethics Committee at the London Sport Institute, Middlesex University.

Procedures

A standardised dynamic warm up was conducted prior to each session consisting of dynamic stretches to the lower body (such as multi-planar lunges, inchworms, and 'world's greatest stretch'), in addition to three practice trials at 60, 80, and 100% perceived effort. Two minutes of rest was provided after the final warm up trial before undertaking the first test. It should be noted that although additional metrics could be quantified from the force platform, only comparable metrics across tests were computed given the focus of this study was to establish asymmetry side consistency across the different tests. Finally, although test order was randomised, trials were always conducted on the left limb first.

Unilateral Isometric Squat. A custom built 'ISO rig' (Absolute Performance, Cardiff, UK) was used for this test protocol. A goniometer was used to measure ~140° of hip and knee flexion (14) for each participant, with full extension of the knee joint equalling 180°. The fulcrum of the goniometer was positioned on the lateral condyle of the femur. The stabilisation arm was lined up along the line of the fibula (in the direction of the lateral malleolus) and the movement arm was lined up with the femur (pointing towards the greater trochanter at the hip). The non-stance limb was required to hover next to the working limb, so as to try and keep the hips level during the isometric squat action; thus, aiding balance and stability. Once in position, participants were required to remain motionless for 2-seconds, without applying any upwards force (which was verified by manual detection of the force-time curve in real time). Each trial was then initiated by a "3, 2, 1, Go" countdown and participants were instructed to try and extend their knees and hips by driving up as "fast and hard as possible" (10) against the bar for three seconds. PF was recorded and was defined as the maximum force generated during the test and reported as absolute values.

Unilateral Countermovement Jump. Participants were instructed to step onto the force plate with their designated test leg with hands placed on hips which were required to remain in the same position for the duration of the test. The jump was initiated by performing a countermovement to a self-selected depth before accelerating vertically as explosively as possible into the air (34). The test leg was required to remain fully extended throughout the flight phase of the jump before landing back onto the force plate as per the set up. The non-test leg was flexed at the hip to ~90° for the duration of each trial. Each trial was separated by 60 seconds of rest. Recorded metrics for each trial included PF (propulsive), eccentric and concentric impulse, with definitions for their quantification conducted in line with suggestions by Chavda et al. (7). Peak propulsive force was defined as the maximum force output during the propulsive phase of the jump. Eccentric impulse was defined as the force exerted multiplied by the time taken to produce it during the eccentric braking phase of the jump. Concentric impulse was defined as the force multiplied by the time taken to produce it during the concentric propulsion phase of the jump (7).

Unilateral Broad Jump. Participants stood on the force plate with their designated test leg and hands placed on their hips. The jump was initiated by performing a countermovement to a self-selected depth before jumping forward as far as possible (34). The fronts of the participants' shoes were placed on the edge of the force plate (without going over) so that the edge of the force plate also served as 0 cm. The tape measure (which was fixed to the floor) ran perpendicular to the force plate for distance to be measured from the heel of the landing foot. Participants were required to "stick the landing" and avoid toppling forward, otherwise trials were excluded and subsequently retaken after a 60-second rest interval. Recorded metrics included PF, eccentric and concentric impulse respectively.

Statistical Analyses

Initially all force-time data were exported to Microsoft Excel™, expressed as means and standard deviations (SD), and later transferred into SPSS (V.24, Chicago, IL, USA) for additional analyses. Within-session reliability was quantified for each metric in both test sessions using the coefficient of variation (CV: SD[trials 1-3]/average[trials 1-3]*100) and intraclass correlation coefficient (ICC) with absolute agreement. CV values < 10% were deemed acceptable (9) and ICC values were interpreted in line with suggestions by Koo and

Li, (22) where scores > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor. Noting that asymmetries may favour either the left or right limbs, a Kappa coefficient was calculated to determine the levels of agreement between asymmetries for a common metric across two tests (8). This method was chosen because the Kappa coefficient describes the proportion of agreement between two methods after any agreement by chance has been removed (8). In addition, only metrics that were common across more than one test were used for this statistic (e.g., PF for all tests). Intuitively, this made sense given that asymmetries have been shown to be both task and metric-specific (4,26,27,28,29). Kappa values were interpreted in line with suggestions from Viera and Garrett (35), where 0.01-0.20 = slight, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-0.99 = almost perfect. Finally, inter-limb asymmetries were quantified as a percentage difference between limbs (from best trials) using the formula proposed by Bishop et al. (4). Given that the quantification of asymmetry was focused on percentage difference between limbs, no reference value was required (4). In addition, it has been suggested that the easiest way to utilise this formula is in Microsoft Excel™ (4); thus, a modification was made via the use of an 'IF function' (Equation). Consequently, if an asymmetry score was positive, the right limb had the largest score between limbs and vice versa for a negative asymmetry outcome (19).

Equation: ((100/(maximum value))*(minimum value)*-1+100)*IF(left<right,1,-1)

RESULTS

Mean values, asymmetries, and reliability data are presented in Table 1. Results showed moderate to excellent reliability (ICC) and acceptable consistency (CV) for each test and metric. Levels of agreement for inter-limb asymmetry scores were calculated using the Kappa coefficient and are shown and described in Table 2. Results showed slight to fair levels of agreement (range = -0.34 to 0.32) for all comparisons with the exception of concentric impulse between the SLCMJ and SLBJ (0.79) which showed substantial levels of agreement. Individual asymmetry values for PF (across all tests) are shown in Figure 1, and for eccentric and concentric impulse for the SLCMJ and SLBJ in Figure 2. It has been suggested that asymmetries may only be 'real' if greater than the test variability (3,5,12), which in this study is represented by the CV value. Thus, the reader is encouraged to pay particular attention to Figures 1 and 2 where the asymmetry bars surpass the dotted line (which represents the largest CV value for those given metrics).

*** INSERT TABLES 1-2 ABOUT HERE ***

*** INSERT FIGURES 1-2 ABOUT HERE ***

DISCUSSION

The aim of the present study was to show whether inter-limb asymmetries were favoured for the same limb during the unilateral isometric squat, SLCMJ and SLBJ tests. Test reliability was generally good to excellent; however, levels of agreement for measures of peak force, eccentric and concentric impulse across tests was poor, with the exception of concentric impulse between the SLCMJ and SLBJ. This was also represented by individual asymmetry analyses (Figures 1-2). These data indicate that asymmetries are test-specific, highly individual in nature, and rarely favour the same limb when comparing across tests.

Mean scores, mean asymmetry, and reliability data are presented in Table 1. When asymmetry values are considered, previous research has suggested that ~10% might be considered a potential threshold where reductions in performance (6) and heightened injury risk occur

(23,32). Therefore, mean asymmetry values in the present study can be considered small. Of note though (and although these mean values are small), it is interesting to see all jumping-based asymmetry values favour the left limb (as represented by negative scores) and the isometric squat favouring the right limb (positive asymmetry outcome). Thus, the asymmetry values alone highlight how one limb may be favoured over the other from task to task. Although somewhat anecdotal, it is plausible that the majority of subjects' right limb was their dominant (often defined by the preferred kicking limb) (15,16,17), which has been shown to be outperformed by the non-dominant limb in previous research (13,15). However, due to the wide range of sporting experience from the present sample and the calculation of asymmetry focused on a percentage difference at a given time point, no reference value (i.e., dominant vs. non-dominant) was defined.

Table 2 shows the results of the Kappa agreement between metric analysis. The Kappa coefficient describes the proportion of agreement between two methods after any agreement by chance has been removed (8). In the present study, PF was a common metric across all tests; thus, asymmetry values were comparable (Figure 1). Noting that the present study aimed to determine how common it was for asymmetries to be present on the same limb, the Kappa values highlight slight to fair levels of agreement for PF asymmetries. For example, if an asymmetry was favoured on the right limb during the SLCMJ, it was likely that the right limb was not favoured during the isometric squat (Kappa = 0.04) or SLBJ (Kappa = 0.05), remembering that this statistic removes the possibility that this agreement may have occurred by chance. Where jumps were concerned, eccentric and concentric impulse metrics were comparable; thus, asymmetry scores for these metrics were compared (Figure 2). Of note, a comparison between concentric impulse across both jumps showed substantial levels of agreement, indicating that asymmetries for this metric were often present on the same side. This may indicate that a similar strategy was adopted prior to take off regardless of whether the focus was maximal jump height or distance. As a result, asymmetries often appear to be affected in the same way for this metric during vertical and horizontal jumping tasks. When all other comparisons were drawn for impulse asymmetries, slight to fair levels of agreement were present, again highlighting the individual nature of asymmetries across tests. This is in agreement with previous research (4,29), although to the authors' knowledge, levels of agreement in respect to asymmetries are limited to date (24,25). These results demonstrate the changing nature of asymmetries from test to test, and highlights the need for a more individual approach to data analysis.

Individual asymmetry data for PF and eccentric and concentric impulse measures are shown in Figures 1 and 2 respectively. The largest mean asymmetry value for any test was -5.3%; however, it is clear from both figures that many individual asymmetry values greatly surpassed this. It was not uncommon for asymmetries to be > 10% across all tests with some individuals demonstrating values between 20-30%. If proposed thresholds of ~10% are to be accepted as cut-offs where reduced performance (6) and increased risk of injury are present (23,32), then Figures 1 and 2 also clearly show that many individuals may require training interventions to minimise these differences. In addition, previous literature has suggested that asymmetries should be reported within the context of test variability (CV) so as to determine whether the between-limb difference is outside the associated error of the test (3,4,12). Noting that multiple CV scores exist, the authors chose to represent the greatest CV value for each metric as a proposed threshold (as represented by the dotted lines on Figures 1 and 2) to identify when inter-limb differences fell outside this value. When this is considered, it is again clear that many individuals showed substantial asymmetries in PF (Figure 1) and impulse metrics (Figure 2) as represented by bars surpassing the dotted lines. If mean asymmetry values were interpreted alone, this would not depict the full story of how imbalanced some individuals are; thus, individual data analyses for side-to-side differences appears critical to further our understanding of this concept.

Despite the aforementioned results, readers should be mindful of a couple of limitations. Firstly, the present study used recreational sport athletes; thus, these findings cannot be attributed to elite athlete populations. Furthermore, the very premise of this paper highlights that asymmetries are both task and metric-specific, suggesting that interpreting mean data is somewhat limited. Secondly, this study used a force platform to gather data relating to asymmetries. Although this is not a limitation, it is worth acknowledging that not all practitioners will have access to this equipment. Therefore, an alternative strategy to determine whether asymmetries are favoured for the same limb is required for practitioners governed by smaller budgets. As such, previous work from Bishop et al. (4) used the SLCMJ, single leg hop, triple hop, and crossover hop for distance tests to show the changing nature of asymmetries between tasks. Practitioners who cannot access force platforms could consider such tests to determine whether asymmetries are favoured for the same side during outcome measures such as jump height and distance.

In summary, the results of the present study show that the levels of agreement for asymmetries being present on the same side are quite low and highlights the changing nature of inter-limb differences across tests. In addition, individual asymmetry scores were vastly different to mean values for all metrics and highlights the necessity for a more individualised approach to asymmetry analysis and will likely provide a more complete picture of the presence of inter-limb differences.

PRACTICAL APPLICATIONS

The findings from the present study highlight that asymmetries vary across commonly used strength and jumping-based tests and that the same side is also rarely favoured. As such, practitioners should always consider the individual nature of asymmetries when interpreting data relative to these side-to-side differences. If the mean values alone were used for interpretation, it would suggest that no action would be needed to correct the existing between-limb differences. However, individual asymmetry scores were vastly different and this type of analysis may offer practitioners the chance to implement training interventions to reduce these side-to-side differences on a more individual level. Noting that individualized training programmes can be a challenge when working with large groups of athletes (i.e., in a team sport environment), assessing individual athlete data in respect to asymmetries offers practitioners a viable method of establishing which athletes may require additional exercises to their existing training programme, in an attempt to optimise physical performance and reduce the risk of future injury.

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Table 1: Mean performance data ± standard deviations (SD), asymmetry data, and reliability data for isometric squat, countermovement, and broad jump metrics.

Test/Metric	**Mean ± SD**	**Mean Asymmetry (%)**	**CV (%)**	**ICC (95% Confidence Intervals)**
Iso PF (L)	1597 ± 438 N	0.8	5.4	0.94 (0.88-0.97)
Iso PF (R)	1595 ± 397 N		5.7	0.93 (0.87-0.96)
SLCMJ PF (L)	863 ± 204 N	-3.4	5.8	0.89 (0.80-0.94)
SLCMJ PF (R)	831 ± 182 N		5.3	0.93 (0.87-0.96)
SLCMJ EI (L)	70 ± 17 N·s	-4.2	8.7	0.89 (0.81-0.95)
SLCMJ EI (R)	67 ± 17 N·s		9.1	0.83 (0.71-0.91)
SLCMJ CI (L)	152 ± 21 N·s	-1.6	3.3	0.92 (0.86-0.96)
SLCMJ CI (R)	150 ± 20 N·s		4.1	0.81 (0.69-0.90)
SLBJ PF (L)	732 ± 156 N	-1.4	8.7	0.75 (0.59-0.86)
SLBJ PF (R)	722 ± 159 N		9.3	0.80 (0.66-0.89)
SLBJ EI (L)	59 ± 19 N·s	-5.3	11.9	0.85 (0.74-0.92)
SLBJ EI (R)	56 ± 17 N·s		11.1	0.87 (0.77-0.93)
SLBJ CI (L)	104 ± 17 N·s	-1.4	7.3	0.69 (0.51-0.83)
SLBJ CI (R)	102 ± 14 N·s		8.8	0.66 (0.47-0.81)

CV = coefficient of variation, ICC = intraclass correlation coefficient, Iso = isometric, SLCMJ = single leg countermovement jump, SLBJ = single leg broad jump, PF = peak force, EI = eccentric impulse, CI = concentric impulse, L = left, R = right, N = newtons, N·s = newton seconds.

Table 2: Kappa values and descriptive levels of agreement between the favored and non-favored sides for peak force, and eccentric and concentric impulse metrics across common tests.

Test Methods	Kappa Coefficient	Level of Agreement
Peak Force:		
Iso Squat – SLCMJ	0.04	Slight
Iso Squat – SLBJ	-0.34	Fair
SLCMJ – SLBJ	0.05	Slight
Impulse:		
SLCMJ Ecc – SLBJ Ecc	0.32	Fair
SLCMJ Con – SLBJ Con	0.79	Substantial
SLCMJ Ecc – SLCMJ Con	0.07	Slight
SLBJ Ecc – SLBJ Con	< 0.01	Slight
SLCMJ Ecc – SLBJ Con	0.21	Fair
SLBJ Ecc – SLCMJ Con	-0.25	Fair
Iso = isometric, SLCMJ = single leg countermovement jump, SLBJ = single leg broad jump, Ecc = eccentric, Con = concentric		

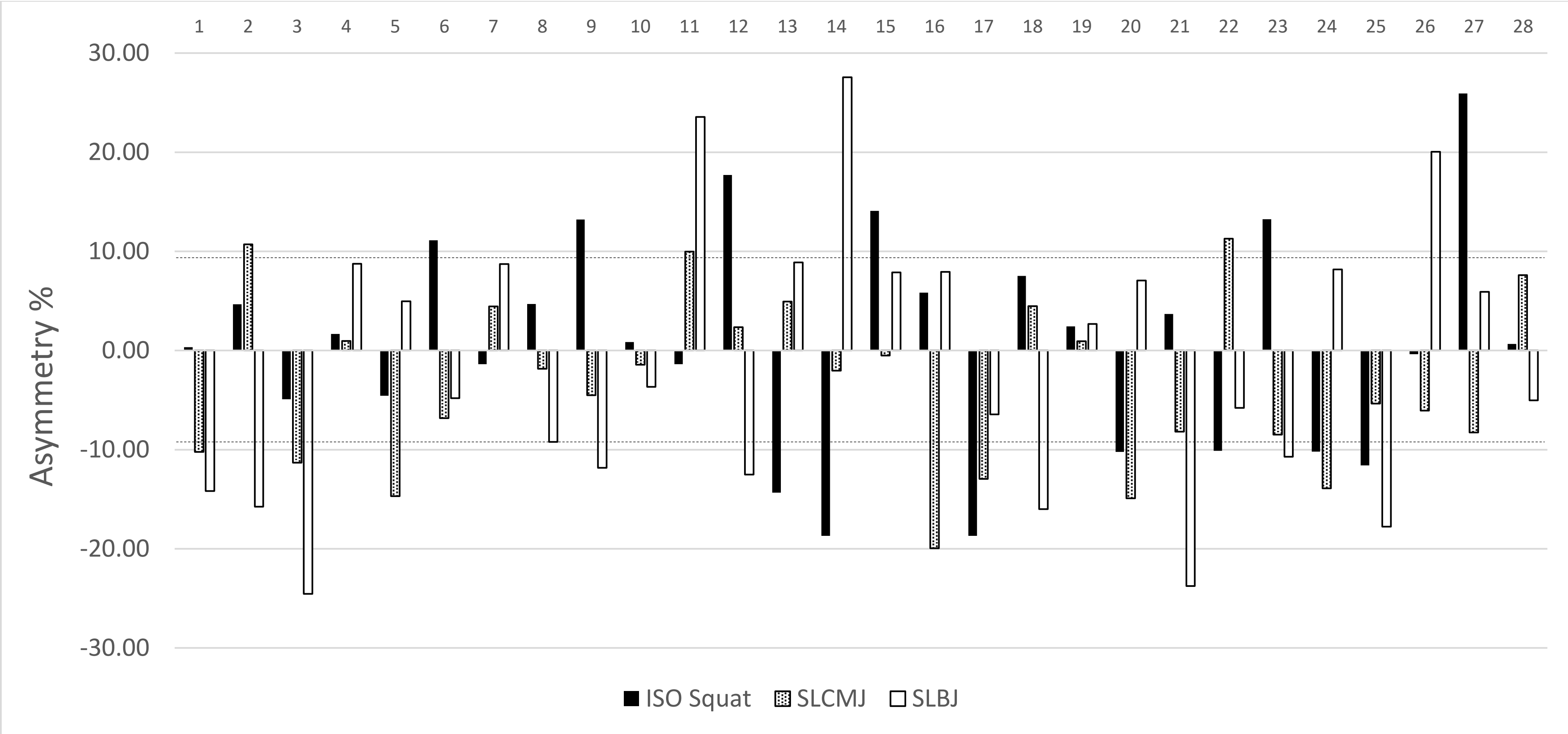

Figure 1: Individual asymmetry data for peak force (PF) during the isometric squat (ISO Squat), single leg countermovement jump (SLCMJ), and single leg broad jump (SLBJ). Note: above the line indicates raw score is greater on the right limb and below the line indicates raw score is greater on the left limb. Dashed lines indicate largest coefficient of variation value for all PF measures.

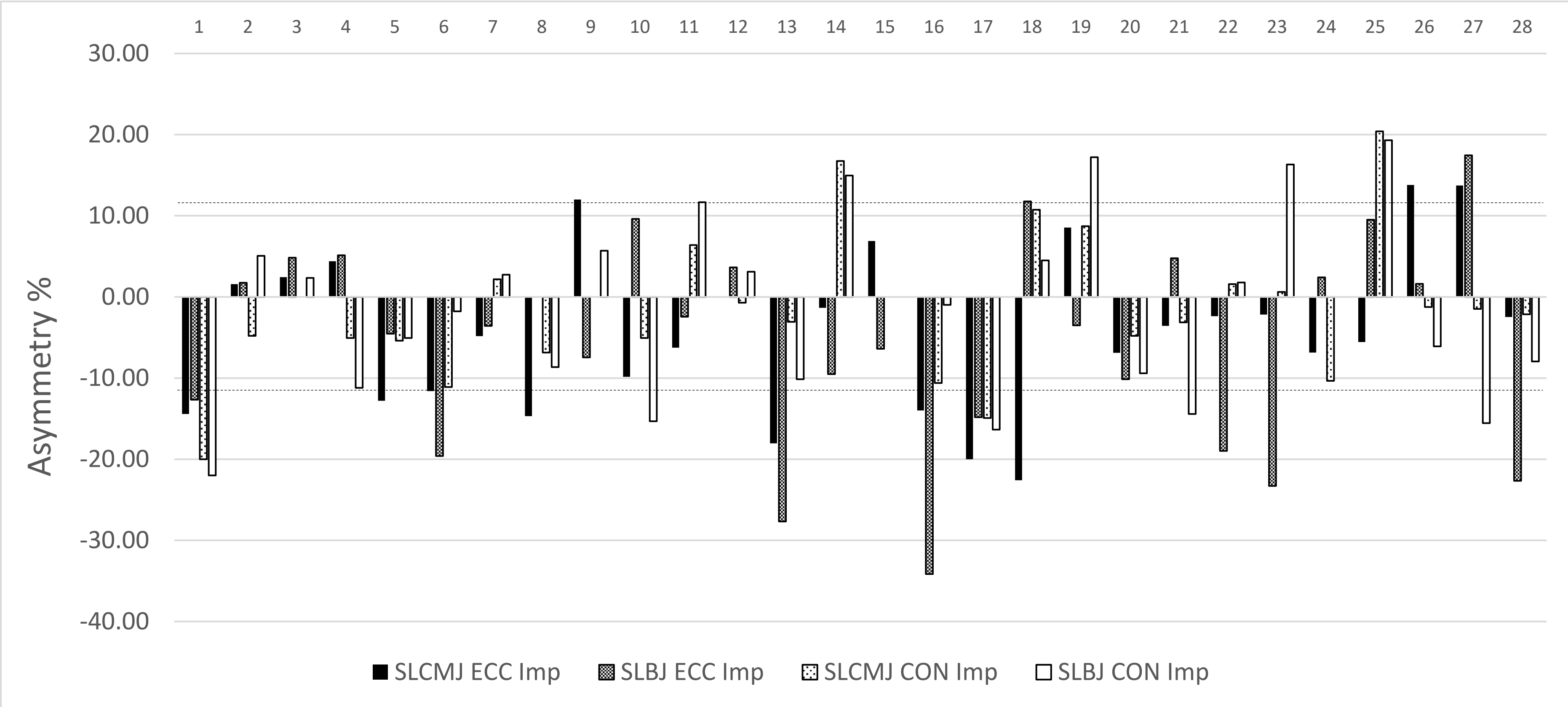

Figure 2: Individual asymmetry data for eccentric (ECC) and concentric (CON) impulse (Imp) during the single leg countermovement jump (SLCMJ) and single leg broad jump (SLBJ) tests. Note: above the line indicates raw score is greater on right limb and below the line indicates raw score is greater on left limb. Dashed lines indicate greatest coefficient of variation value for either eccentric or concentric impulse measures.