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INTER-LIMB ASYMMETRIES: UNDERSTANDING HOW TO CALCULATE DIFFERENCES FROM BILATERAL AND UNILATERAL TESTS

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ABSTRACT

Inter-limb asymmetries have been a popular topic of investigation in the strength and conditioning literature. Recently, numerous equations have been highlighted that can quantify these between-limb differences. However, no distinction was provided on whether their use was applicable to both bilateral and unilateral tests. This article provides a framework for selecting the most appropriate asymmetry equation based on the selected test method, ensuring accurate calculation and interpretation. In addition, considerations for data analysis have also been included as a guide for practitioners on the relevance of monitoring inter-limb differences longitudinally.

Key Words: Double leg, formulas, single-leg, symmetry

INTRODUCTION

Inter-limb asymmetries have been a common source of investigation in recent years and refers to the concept of comparing the function of one limb in respect to the other. A recent systematic review examining the effects of between-limb differences on physical and sporting performance demonstrated equivocal findings [8]. In summary, larger lower limb asymmetries in strength may be indicative of reduced jumping ability and power output [1,22]; however, when these differences are quantified during jumping tasks, their effect on locomotive activities appears inconclusive [13,16,18]. From an injury perspective, older literature has suggested that an asymmetry threshold of > 15% marks the point of heightened risk [3,20]. However, much of the available literature has drawn this conclusion from identifying ~15% differences in healthy subjects, and there is currently a paucity of evidence to support this notion using prospective cohort analysis. Given the inconsistency in these findings, further research is warranted to examine the effects of asymmetry on both injury and performance-based outcomes.

Multiple methods exist to quantify inter-limb asymmetries and will likely be dictated by a range of factors [7,8,9]. Such considerations include the needs of the athlete, availability of testing equipment, and reliability of the chosen test [9]. Once these factors have been accounted for (and assuming an asymmetry profile is required), practitioners must consider whether inter-limb differences are best quantified bilaterally or unilaterally. The needs analysis of the athlete or sport will provide some clarification to this question and determine if both methods are utilized as part of an athlete test battery. Once the appropriate tests have been selected, an asymmetry profile can be created; however, it is essential that the calculation used to quantify between-limb differences matches the specifics of the test method.

Recent literature has critically examined the utility of commonly used equations to quantify inter-limb asymmetries [7]. However, no distinction was made on whether these equations can be used for both bilateral and unilateral tests. Whilst it may not be immediately apparent whether this distinction is required, the authors have proposed that it is warranted and is the primary aim of this paper. In addition, considerations for practitioners are included within. It is intended that the current article provides practitioners with a clear understanding of how to select the appropriate calculation method for both bilateral and unilateral tests, and some considerations for interpreting the results. Consequently, this will allow for meaningful decisions to be made regarding whether the measured deficits are 'real' and thus aid in a more appropriate monitoring process long-term.

EQUATIONS TO CALCULATE INTER-LIMB ASYMMETRIES

Recent literature [7] has highlighted nine possible equations to quantify inter-limb asymmetries (Table 1). With multiple formulas available, definitive conclusions pertaining to the most appropriate one is not always apparent. Furthermore, with such inconsistencies present, comparisons across the literature regarding asymmetry thresholds and their associated effects on physical performance or injury risk are almost impossible to conclude. Therefore, a more consistent approach to asymmetry calculation is warranted so that results are comparable over time. Once the appropriate equation has been identified, it is assumed that it can be applied to any test that quantifies inter-limb asymmetries, whether it is bilateral or unilateral. However, this is not necessarily the case and this point can be illustrated by examining the force-time curves of bilateral (CMJ) and unilateral (SLCMJ) countermovement jumps respectively.

*** INSERT TABLE 1 ABOUT HERE ***

QUANTIFYING ASYMMETRIES DURING BILATERAL TESTS

Figure 1 shows two separate vertical force traces (one for each limb) during the CMJ. At this point, it should be noted that assuming data can be obtained for each limb, a variety of metrics can be quantified, but in this instance we discuss net peak vertical ground reaction force (vGRF). For this example, the green line represents both the left/non-dominant limb and the red one the right/dominant limb. The subject's bodyweight is 800 Newtons (N) with an average of 420 and 380 N being distributed on the right and left limbs respectively during the quiet standing period (1-2 seconds), prior to the initiation of the jump. When these figures are accounted for (by subtracting from the peak propulsive force value labeled in the graph), the left limb's force is equal to 405.12 N; the right limb's is 556.61 N making the sum force for the propulsive phase of the jump to be 961.73 N. When 556.61 and 405.12 are divided by 961.73 (and multiplied by 100), 57.88% and 42.12% of the force is being performed by the right and left limbs respectively at that moment. Therefore, the difference between limbs is 151.49 N and when this is divided by the sum force (and multiplied by 100) an asymmetry of 15.75% exists in this example.

*** INSERT FIGURE 1 ABOUT HERE ***

Essentially, because any differences in force between limbs are always relative to the sum force value, we cannot choose most of the suggested equations in Table 1. Doing so would create a different asymmetry outcome; one that is inaccurate relative to the sum force (as portrayed in Table 2). It should be noted that the authors have not shown all possible outcomes in Table 2. Noting that only four different outcomes are possible from all nine equations (Table 1), the authors have chosen to select four that will produce different values regardless of the data applied to the formulas. Therefore, when quantifying inter-limb asymmetries during bilateral tests, it appears that the only two equations which correctly calculate the 15.75% asymmetry value specifically, the Bilateral Asymmetry Index 1 (BAI-1) and Symmetry Index (SI). However, it should be noted that the SI defines limbs via highest and lowest scores which may be prone to change depending on factors such as injury history and training or competition requirements [27]. Whilst this equation will always quantify bilateral asymmetries accurately, practitioners should be mindful of the highest score changing between limbs. Therefore, the BAI-1 may be the more appropriate equation for quantifying asymmetries during bilateral tests, which has been suggested previously [7].

*** INSERT TABLE 2 ABOUT HERE ***

QUANTIFYING ASYMMETRIES DURING UNILATERAL TESTS

Figures 2 and 3 provide example force traces for the SLCMJ on the right and left limbs respectively for the same subject seen in Figure 1. Given the similarity in movement, naturally the traces look similar to that of the CMJ and in this example the same participant has been used. Once body mass is taken into consideration (subtracting 800 N), net peak vGRF for the right limb (Figure 2) is 679.69 N and 397.76 N on the left.

Initially, it may be thought that less restriction applies as to which equation can be used to calculate the inter-limb asymmetry in vGRF. Given that the SLCMJ is a unilateral test, no contribution exists from the opposing limb and the force is distributed solely on the designated test leg potentially providing a more accurate representation of ‘true’ inter-limb asymmetries [5,9]. However, practitioners should be mindful that some of the equations presented in Table 1 still provide an inaccurate asymmetry score. Noting that an asymmetry is merely a percentage difference between limbs at a given time point, it is surprising to see such variation in values. Using the SLCMJ example, the percentage difference between the right (679.69 N) and left (397.76 N) scores is 41.48%. This can be computed by an alternative equation which merely expresses the difference between these values as fractions of 100%.

Percentage difference: 100/(max value)*(min value)*-1+100

SLCMJ example (Figures 2 and 3): 100/(679.69)*(397.76)*-1+100 = 41.48%

Using the percentage difference method, once the minimum value has been computed, this will provide an outcome of symmetry (in this instance 58.52%). Multiplying by -1 and then adding 100, simply moves the value to the opposite end of the spectrum, creating an asymmetry score of 41.48%. Similar to the CMJ example, the same four equations have been used in Table 3. Any equation from Table 1 that does not produce an outcome of 41.48% for this SLCMJ example is arguably calculating the percentage difference incorrectly. Therefore, the proposed equations to use when quantifying asymmetries from unilateral tests are the BSA or percentage difference method.

*** INSERT FIGURES 2 AND 3 ABOUT HERE ***

*** INSERT TABLE 3 ABOUT HERE ***

PRACTICAL APPLICATIONS

Thus far, this article has made the assumption that practitioners will have access to force plates in order to quantify side-to-side differences. With more affordable and portable versions now readily available, many practitioners will be able to utilise such testing protocols. For those still limited by smaller budgets, smartphone applications such as My Jump [2] still offer a viable alternative for quantifying these differences during unilateral jump tests. However, it should be noted that any associated asymmetry data can only be quantified from unilateral tests and will be governed predominantly by outcome measures (such as jump height or distance). Furthermore, if additional tests such as isometric squats or mid-thigh pulls are to be evaluated from an asymmetry perspective, force plates will be required.

An additional point to consider involves interpreting the asymmetry outcome. Exell et al. [12] highlighted that an inter-limb asymmetry can only be considered 'real' if the value is greater than the intra-limb variability within that specified movement. During testing, variability is quantified via the coefficient of variation (CV) which provides practitioners with an indication of typical error between trials [29]. Thorough testing protocols depict that ~3 trials should be considered when testing athletes so that the CV can be accurately quantified [29]. In the CMJ example used in this article, the asymmetry in peak vGRF is 15.75%. Assuming that the CV was less than the asymmetry value, it could be concluded that the asymmetry score was real. Whilst an asymmetry would still be considered real in this instance with a CV of 10-15%, acceptable CV values have been suggested as < 10% [11]. With that in mind, if variability is calculated as > 10%, practitioners may wish to consider whether their test protocols require refining, further familiarization is needed, instructions were sufficiently clear or whether the athlete's warm up/rest intervals were inadequate [9,29].

Moreover, although recent literature highlighted such issues as being important considerations for reliable asymmetry testing [9], the majority of this information pertains to within-session reliability. Although useful, asymmetries have been suggested to be highly task-specific [12,17]; thus, the notion of longitudinal tracking in respect to asymmetries becomes arguably more important, as noted in previous literature [8]. For example, if the notion of task-specificity is accepted, it is plausible that test protocols can remain consistent within each test session (with CV values < 10%), but the asymmetry outcome may vary considerably. At present, the distinct lack of longitudinal data relating to asymmetries make suggestions on this issue somewhat anecdotal. However, previous asymmetry literature has highlighted the use of the smallest worthwhile change (SWC) as a tool to detect changes in scores over time [7]. Computed by multiplying the between-subject standard deviation by 0.2 [7,29], the SWC may provide an indication of a true change. This can be taken one step further with the use of the effect size statistic which will provide insight into the magnitude of change during the monitoring process [29].

Thus, practitioners are advised to report and compare asymmetries in respect to testing variability (CV) which may provide an insight into whether they are real. In addition, longitudinal tracking of inter-limb differences is currently lacking in the literature; therefore, practitioners are advised to consider how these scores fluctuate over time. The use of the SWC and effect sizes may assist in outlining whether targeted training interventions are required.

CONCLUSION

In summary, bilateral or unilateral tests can be used to quantify inter-limb asymmetries. If bilateral tests are selected, it is important that the appropriate equation is selected given that between-limb differences are always presented in relation to the sum total for any reported metric. The BAI-1 and SI appear to be the only formulas that will accurately quantify asymmetries during bilateral tasks. If unilateral tests are selected, the BSA or percentage difference method accurately calculates inter-limb differences and should be the chosen formulas. Finally, the interpretation of asymmetry scores is an important consideration. A comparison with test variability and longitudinal tracking of these differences may be crucial to understanding their importance as part of a continued monitoring process with athletes.

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Table 1: Different equations for calculating asymmetries using hypothetical jump height scores of 25 and 20cm (taken from Bishop et al. [7] and re-used with permission from Wolters Kluwer).

Asymmetry Name	**Equation**	**Asymmetry (%)**	**Reference**
Limb Symmetry Index 1 (LSI-1)	(NDL/DL) x 100	80	Ceroni et al. [10]
Limb Symmetry Index 2 (LSI-2)	(1 – NDL/DL) x 100	20	Schiltz et al. [25]
Limb Symmetry Index (LSI-3)	(Right – Left)/0.5 (Right + Left) x 100	22.22	Bell et al. [4] Marshall et al. [19]
Bilateral Strength Asymmetry (BSA)	(Stronger limb – Weaker limb)/ Stronger limb x 100	20	Nunn et al. [21] Impellizzeri et al. [14]
Bilateral Asymmetry Index 1 (BAI-1)	(DL – NDL)/ (DL + NDL) x 100	11.11	Kobayashi et al. [15]
Bilateral Asymmetry Index 2 (BAI-2)	(2 x (DL – NDL)/ (DL + NDL)) x 100	22.22	Wong et al. [30] Sugiyama et al. [28]
Asymmetry Index (AI)	(DL – NDL)/ (DL + NDL/2) x 100	22.22	Robinson et al. [23] Bini et al. [6]
Symmetry Index (SI)	(High – Low)/ Total x 100	11.11	Shorter et al. [26] Sato and Heise, [24]
Symmetry Angle (SA)	(45° – arctan (L/R))/90° x 100	7.04	Zifchock et al. [31]

DL = Dominant limb, NDL = Non-dominant limb

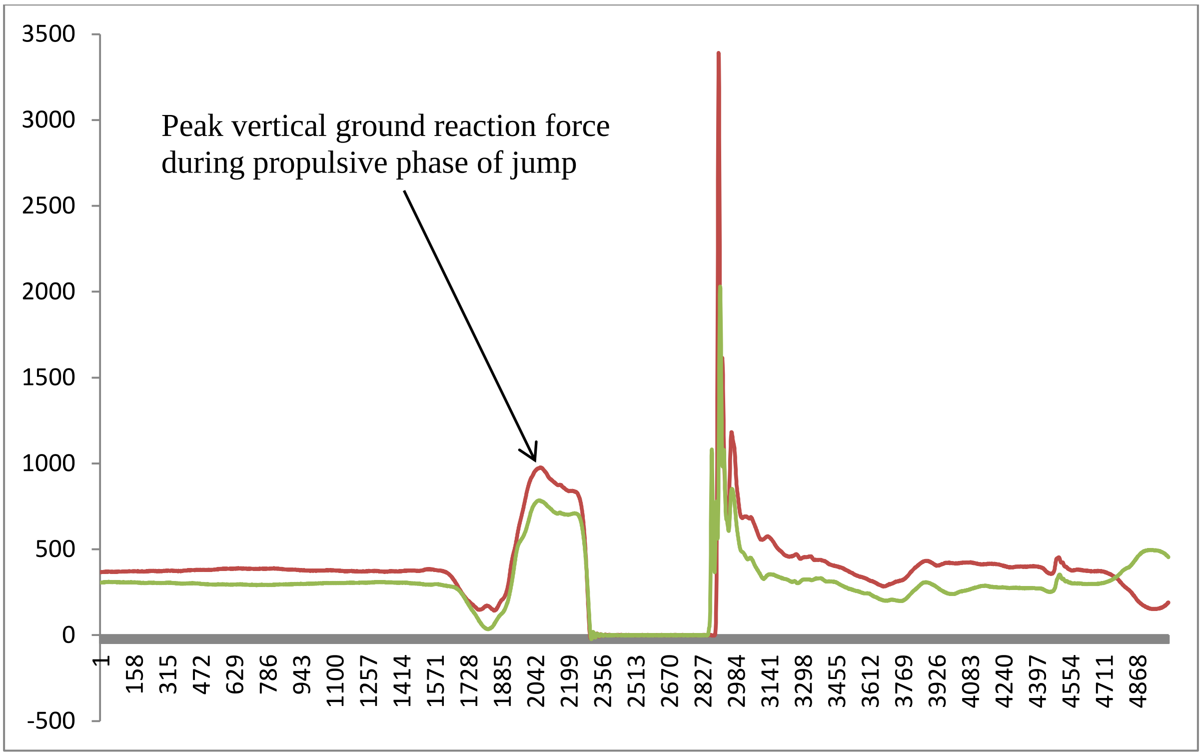
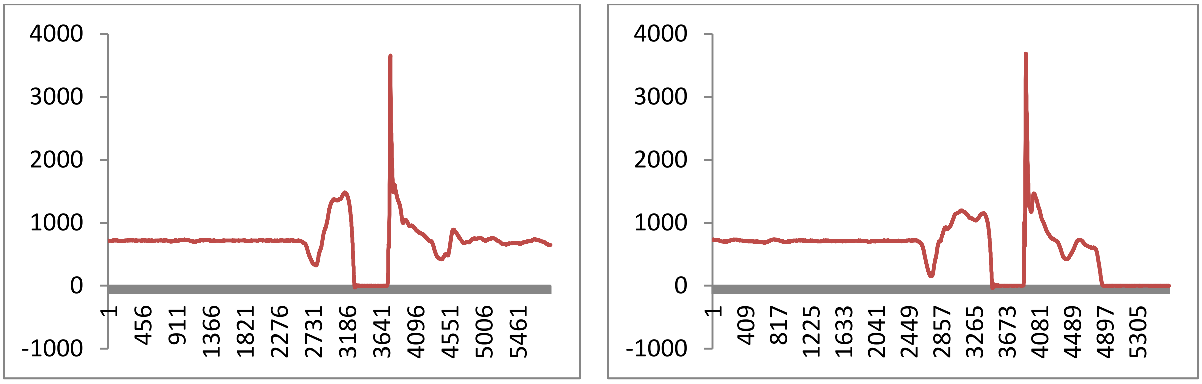


Figure 1: Example force trace for each limb during a CMJ (extracted from PASCO Capstone software). Red line denotes right/dominant limb, green line denotes left/non-dominant limb.

Table 2: Asymmetry values for the CMJ data using different equations (which has an accurate inter-limb asymmetry of 15.75%).

Asymmetry Name	**Equation**	**Asymmetry (%)**
Bilateral Strength Asymmetry	(556.61 – 405.12)/556.61 x 100	27.22
Bilateral Asymmetry Index 1	(556.61 – 405.12)/556.61 + 405.12) x 100	15.75 *
Bilateral Asymmetry Index 2	(2 x (556.61 – 405.12)/(556.61 + 405.12)) x 100	31.50
Symmetry Angle	(45 – arctan (405.12/556.61))/90 x 100	9.95

* denotes that the outcome is accurate to the CMJ data



Figures 2 and 3: Example force traces for the SLCMJ. Figure 2 represents the right/dominant limb and Figure 3 for the left/non-dominant limb.

Table 3: Asymmetry values for the SLCMJ data using different equations (which has an accurate inter-limb asymmetry of 41.48%).

Asymmetry Name	**Equation**	**Asymmetry (%)**
Bilateral Strength Asymmetry	(679.69 – 397.76)/679.69 x 100	41.48 *
Bilateral Asymmetry Index 1	(679.69 – 397.76)/(679.69 + 397.76) x 100	26.17
Bilateral Asymmetry Index 2	(2 x (679.69 – 397.76)/(679.69 + 397.76)) x 100	52.16
Symmetry Angle	(45 – arctan (397.76/697.69))/90 x 100	16.36