ASYMMETRIES OF THE LOWER LIMB: THE CALCULATION CONUNDRUM IN STRENGTH TRAINING AND CONDITIONING

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ABSTRACT

Asymmetry detection has been a topic of interest in the strength and conditioning (S&C) literature with numerous studies proposing many different equations for calculating between-limb differences. However, there does not appear to be a clear delineation as to which equation should be used when quantifying asymmetries. Consequently, the authors have uncovered nine different equations which pose confusion as to which method the S&C specialist should employ during data interpretation. This article aims to identify the different equations currently being used to calculate asymmetries and offer practitioners a guide as to which method may be most appropriate when measuring asymmetries.

Key Words: Asymmetries, lower limb, equations, symmetry angle

INTRODUCTION

The concept of asymmetries has been the topic of numerous research studies, some of which have identified that such a phenomenon is detrimental to performance (4, 10, 12). Asymmetries in power ~10% have been shown to result in a loss of jump height (4), and slower change of direction speed times (12), suggesting it would be beneficial to minimise these differences. For such a widely researched concept, it is surprising that few studies have offered a definition of this term. However, Keeley et al. (16) propose that "Asymmetrical strength across the lower extremities can be defined as the inability to produce a force of contraction that is equal…". Whilst the majority of studies refer to the differences between limbs, it is important to understand that this is not always the case. Intra-limb variations (differences within the same limb) will be evident when performing repeated athletic tasks and are most likely magnified during maximal efforts. Consequently, Exell et al. (8) suggest that asymmetry can only truly be classified as "real" if the between-limb difference is greater than the intra-limb variation.

Typically, asymmetries have been reported as a percentage with distinctions being made between dominant and non-dominant, right and left, stronger and weaker, or preferred and un-preferred limbs. These distinctions provide different "reference values", thus allowing asymmetries to be calculated for a given test or variable. However, the wide variety in such reference values may have an effect on the result being conveyed. For example, an athlete may state that their right limb is their dominant, but if scores are inputted into an equation using the stronger and weaker classification, a different score may be reported if the stronger limb is not the dominant limb. Furthermore, if the stronger and weaker method is used, data interpretation over extended periods of time may lose context particularly as higher scores can change as a result of injury occurrence (34). Consequently, the reference value will have a profound effect on the asymmetry result, emphasising the importance of distinguishing between the different methods of calculations noted in the body of available research to date.

Thus far, relatively simple tests such as the back squat (9, 11, 23, 30), countermovement jumps (CMJ) (4, 14, 39), single leg countermovement jumps (6, 15, 16), and single leg hops (2, 22, 24, 26, 28, 29) have proven to be reliable and effective methods for detecting asymmetries in the field. In addition, laboratory-based tests such as the isometric squat or mid-thigh pull (1, 3, 34) and isokinetic quadriceps and hamstring testing (7, 10, 21) have also been used to quantify between-limb differences. In essence, it would appear that the strength and conditioning (S&C) specialist can determine such differences in a number of ways. Moreover, should practitioners wish to calculate the level of asymmetry, the test(s) chosen to do so will likely need to retain specificity of both the sporting needs analysis and the requirements of the athlete.

While the validity and test-retest reliability of different testing protocols to measure asymmetry has been examined, what is less clear, is which equation should be used when aiming to quantify these differences. Since the late 1980's (when interest in asymmetries first appeared to be published), there have been a wide variety of equations proposed in the literature (5, 20, 25, 27, 31, 32, 35, 38, 40). In more recent study methodologies, it becomes increasingly clear that some "adopt" a specific equation purely by citing from earlier literature. The number of variations in equations used would indicate that further distinction and understanding between them is warranted. By doing so, this will allow practitioners to ensure optimal validity in their asymmetry calculations which may have profound effects on program prescription.

This review will provide the S&C specialist with an overview of the different equations that have been used to calculate asymmetries to date. Where possible, it will critically evaluate each method in an attempt to provide practitioners with some guidance and consistency on the topic of asymmetry detection moving forward.

EQUATIONS USED TO CALCULATE ASYMMETRIES

In order to provide the reader with some context as to how these equations differ, a hypothetical example of jump height is provided. In this instance, jump height scores of 25 and 20cm will be used for each limb making the assumption that the larger score corresponds to the dominant, right and/or stronger limb where appropriate (Table 1). However, it should be noted that the following example is purely hypothetical and athlete scores will not always follow this assumption. Furthermore, each equation has been provided with an acronym by the authors. This is because some studies have referred to different equations by the same name, thus differentiating between each variation is necessary to provide a clear distinction. Finally, the authors stress that the reader should address Table 1 carefully as there are some very subtle differences between some of the equations.

INSERT TABLE 1 ABOUT HERE

When referring to the asymmetry score column, it is evident that there is great disparity between the nine identified methods. On first view, there is no obvious choice between them, particularly if more than one equation brings about the same score. However, a deeper analysis of the asymmetry literature does provide practitioners with some indication of strengths and weakness between the proposed methods.

INTERPRETING THE EQUATIONS

Table 1 shows some equations produce the same asymmetry result regardless of their differences, thus some distinction is required to guide the S&C specialist through the best way of determining between-limb differences in performance. As such, equations that produce the same score have been grouped together for further discussion.

LSI-1, LSI-2 & BSA

The first method (LSI-1) used by Ceroni et al. (6) is actually a measure of limb symmetry, rather than asymmetry. When compared to LSI-2, the results, although very different, are simply a matter of which end of the "asymmetry spectrum" is being calculated, with the second focusing on asymmetry levels for a given test. The BSA equation employed by Impellizzeri et al. (14), was used as a method for calculating asymmetries during a bilateral CMJ and although the equation is again slightly different, the results will produce the same level of asymmetry as LSI-1 and LSI-2. However, there are potential limitations in the BSA equation. The result of always putting the stronger score first is that positive values will always be obtained which poses issues surrounding longitudinal analysis. There is the possibility that the stronger limb could become weaker at a later testing date, yet the criteria used in this equation do not take this into consideration. It is therefore the suggestion of the authors that when calculating asymmetries, dominant and non-dominant limbs are clearly defined. Whilst dominant and non-dominant limbs will still be subject to changes in scores, those changes will not affect which limb is the dominant one for an athlete. Therefore, should a lower score be obtained by the dominant limb in any given test, this will be reflected in a negative sign for the asymmetry result. Consequently, considering the LSI-2 and BSA equations produce the same asymmetry percentage, yet the former has provided a more consistent distinction between limbs, it is suggested that this method may hold an advantage between the two when interpreting data scores.

LSI-3, BAI-2 and AI

Other comparable results are seen for LSI-3, BAI-2 and the AI. There are subtle differences in each of the equations; however, once again each one produces the same asymmetry score. With that in mind, it is perhaps only the LSI-3 equation that practitioners could consider removing as a calculation option. Bell et al. (4) defined the asymmetry distinction between "right and left" which will produce the same result as the other two options. However, some sports such as Fencing which are very asymmetrical in nature (37) will most likely dictate which leg is dominant in key actions such as lunging; thus, this distinction will provide more context when reporting scores. Consequently, it would seem plausible to use either the BAI-2 or AI should these equations be accepted for asymmetry detection.

BAI-1 and SI

These two equations produce substantially smaller asymmetry scores than any of the previously discussed methods. Once again, their use in more recent studies would appear to be a by-product of previously cited research as opposed to identifying whether the method itself is appropriate for the required analysis or not. The SI only calculates asymmetries via the highest and lowest score, which again may be prone to change depending on factors such as injury history and exposure to training or competition (33). Therefore, data collected over extended periods of time could result in the context of asymmetries being lost if different limbs produce the highest score. It is therefore the suggestion of the authors that the BAI-1 may hold an advantage over the SI when calculating asymmetries. However, similar to prior conclusions, any comparison between the BAI-1 and any previously suggested methods requires further research and is subject to the context in which these equations are being used.

The Symmetry Angle (SA)

This method of calculating asymmetries is somewhat different to all the previously discussed equations. It was first suggested by Zifchock et al. (40) and provides a degree of asymmetry away from an optimal angle of 45° (see Figure 1). This is created when two values are plotted against each other forming a vector in relation to the x-axis. Essentially, two identical values would create a 45° angle in relation to the x-axis and thus perfect symmetry (40). However, for ease of interpretation, the result can then be multiplied by 100 converting it to a percentage, which is then comparable to all other equations (with a score of 0% indicating perfect symmetry). Zifchock's rationale for the symmetry angle was that all other methods require a 'reference value' of some sort and that this value is dependent on the question being asked. For example, if a comparison between the stronger and weaker leg is made, equations seem to have adopted the stronger leg as the reference value – as per the equation used by Nunn et al. (25) and Impellizzeri et al. (14). However, no justification has been noted for this and if the weaker limb was chosen as the reference value, asymmetry scores would be different. Secondly, a logical reference value may present itself when determining scores for injured populations or when a sport has a clear dominant and non-dominant side. However, healthy, non-sporting populations pose no clear limb to be used for this reference value, therefore a more robust method for calculation is warranted that can be applied to all scenarios. Finally, asymmetry scores have been seen to be "artificially inflated" again, due to an inappropriate reference value being implemented into the equation (40). It must be noted at this point that should a logical reference value (such as which limb is dominant) exist, it may be that one of the previously suggested asymmetry calculations would be appropriate. Such an example could be in sports such as Fencing, where the dominant limb will always be considered to be the "lead leg" due to the asymmetrical nature of the sport (37).

INSERT FIGURE 1 ABOUT HERE

Subsequently, Zifchock proposed that the SA was immune from these issues, thus proving to be a more appropriate method for identifying asymmetries. However, it should be acknowledged that the only comparison drawn was against the equation proposed by Robinson et al. (27). At this point, should the reasons in favour of the SA be accepted, this would perhaps prove to be the logical equation choice over all others when attempting to calculate asymmetries, and this is a notion that is supported with recent studies (18, 19).

PRACTICAL APPLICATIONS

The evidence presented would suggest that the SA is the most apt method for calculating asymmetries moving forward. As Table 1 shows, the SA result is substantially smaller than all other equations – remembering that the outcome is immune to both reference values and over-inflated scores. Considering asymmetries can be determined by a vast array of exercises (as described in the introduction), the SA equation can be easily implemented into data analysis by all practitioners aiming to monitor this characteristic. Consequently, the data analysis in Microsoft Excel™ for this hypothetical example is as follows:

Step 1: =DEGREES(ATAN(20 ÷ 25)) = 38.66

Step 2: ((45 – 38.66)÷90) x 100 = 7.04%

Typical assessments during physical testing batteries include single leg countermovement jumps and single leg hops due to their ease of implementation and associated low cost. Thus, the SA could be easily utilised to determine between-limb differences during these commonly-used tests. Similarly, alternative lab-based assessments such as isometric mid-thigh pulls or even strength exercises such as the back squat can be accompanied by SA data analysis, providing force plates are accessible. As such, there would appear to be no major limits to how asymmetries are assessed and therefore no reason why the SA cannot be used in the subsequent analysis. Furthermore, the limited information surrounding their effects on performance would indicate that this is an area that warrants further research. Therefore, it is the suggestion of the authors that practitioners consider the SA as the chosen method when calculating asymmetries during subsequent data analysis and aim to establish whether these functional imbalances have a detrimental effect on performance.

Finally, detecting change is a crucial aspect of data analysis for S&C practitioners as this allows us to objectively determine whether any noted differences are true. There is a distinct lack of research surrounding changes in asymmetry scores over time and to the authors' knowledge, none using the SA method. However, one method of determining such differences in scores (which can be applied in multiple data analyses) is via the smallest worthwhile change (13), which is the smallest change in score that is accepted as ‘real’. Assuming all data are reliable (which will occur from a well-designed protocol during 2-3 test trials), the smallest worthwhile change can be calculated by taking the between-subject standard deviation and multiplying it by 0.2 (36). It should be noted that without multiple asymmetry scores, a hypothetical example cannot be provided here. However, the principle of using the smallest worthwhile change can be used when assessing changes in asymmetry scores for a group of athletes and will allow for a true representation over an extended period of time.

CONCLUSION

Judging by the number of recent studies investigating asymmetries, this would appear to be a topic of interest in S&C research. As with all forms of testing, optimal validity and reliability are essential so that the S&C specialist can have full confidence when analysing data and thus, make informed decisions towards their athletes’ physical preparation. To the authors’ knowledge, distinguishing between equations has not yet been addressed or established, therefore it is difficult to completely justify which method should be used over another. However, the very limited research on this specific topic may indicate that reporting asymmetries via the symmetry angle (SA) method holds some advantages over other options. It would appear to be immune to reference values and inflated scores which may indicate it is a more robust method for asymmetry detection in all populations. In addition, the similarities between all other equations (refer to Table 1) is noticeable with some having only a subtle difference in its methods for their respective calculations. Such similarities are compounded when two or more equations yield the same score, providing no clear choice between them. However, the importance of providing clarity surrounding the issue of reference values would appear to be paramount and an equation that can be applied to all circumstances that is exempt to these issues may offer a more consistent and universal approach to asymmetry detection.

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Table 1: Different equations for calculating asymmetries (using hypothetical jump height scores of 25 and 20cm).

Asymmetry Name	**Equation**	**Asymmetry Score (%)**	**Reference**
Limb Symmetry Index 1 (LSI-1)	(NDL ÷ DL) x 100	80	Ceroni et al. (6)
Limb Symmetry Index 2 (LSI-2)	(1 – NDL ÷ DL) x 100	20	Schiltz et al. (31)
Limb Symmetry Index (LSI-3)	(Right – Left)÷0.5 (Right + Left) x 100	22.2	Bell et al. (4); Marshall et al. (20)
Bilateral Strength Asymmetry (BSA)	(Stronger limb – Weaker limb) ÷ Stronger limb x 100	20	Nunn et al. (25) Impellizzeri et al. (14)
Bilateral Asymmetry Index 1 (BAI-1)	(DL – NDL) ÷ (DL + NDL) x 100	11.1	Kobayashi et al. (17)
Bilateral Asymmetry Index 2 (BAI-2)	{2 x (DL – NDL) ÷ (DL + NDL) x 100	22.2	Wong et al. (38); Sugiyama et al. (35)
Asymmetry Index (AI)	(DL – NDL) ÷ (DL + NDL/2) x 100	22.2	Robinson et al. (27); Bini et al. (5)
Symmetry Index (SI)	(High – Low) ÷ Total x 100	11.1	Shorter et al. (32); Sato and Heise, (30)
Symmetry Angle (SA)	(45° – arctan (L ÷ R)) ÷ 90° x 100	7.04	Zifchock et al. (40)

DL = Dominant limb

NDL = Non-dominant limb

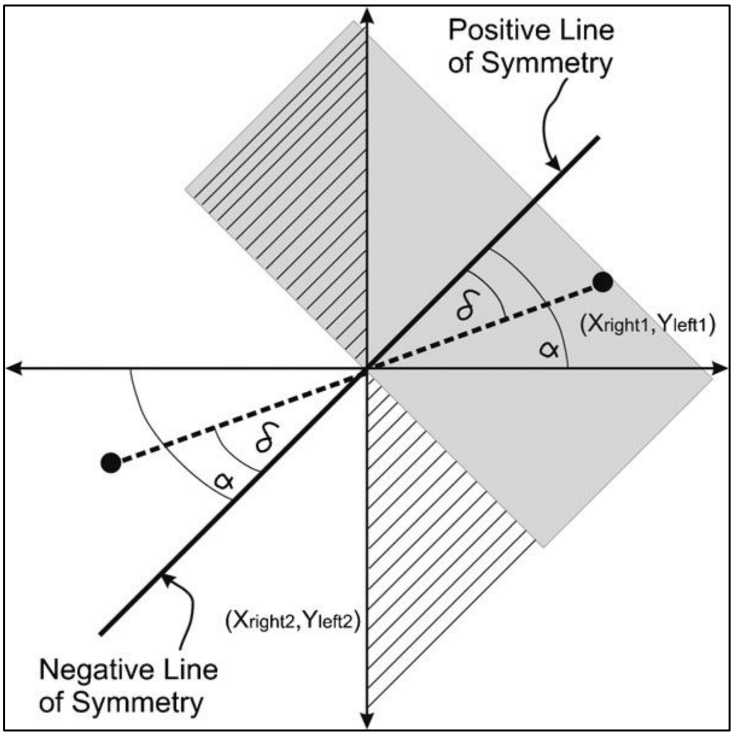

Figure 1: Quantifying asymmetries via the symmetry angle method (figure taken from Zifchock et al. (40) and re-printed with permission from Elsevier Publishing).