# THE SYMMETRY ANGLE IDENTIFIES LESS CLINICALLY RELEVANT INTER-LIMB ASYMMETRIES THAN THE SYMMETRY INDEX IN HEALTHY ADULTS

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There are several methods for calculating inter-limb symmetry, an inter-limb difference ≥15% has been suggested as an indicator of sporting injury risk. The purpose of this study was to compare three common methods for determining symmetry: the Symmetry Index (percentage difference; SI) when referenced to the left limb ($SI_{Left}$) or the average of both limbs ($SI_{Average}$), and the Symmetry Angle (vector difference; SA). 15 recreationally active participants completed a sprint protocol on a non-motorised treadmill. Accelerometers were positioned on both tibias to measure peak resultant acceleration (PRA). The SA identified less clinically relevant PRA inter-limb asymmetries than the SI in healthy adults. Once an appropriate level of asymmetry as measured by the SA is determined, this may help to more correctly identify asymmetry in athletes and patients than the SI.

**KEYWORDS:** Accelerometer, non-motorised treadmill, inertial measurement unit.

**INTRODUCTION:** Measuring biomechanical locomotor asymmetry of the lower-limb is relevant for athletic and general populations because inter-limb differences of ~15% may be indicative of injury risk (Knapik, Bauman, Jones, Harris, & Vaughan, 1991; Zifchock, Davis, & Hamill, 2006). Moreover, lower-limb asymmetry may decrease athletic performance (Bishop, Turner, & Read, 2018). There are several different methods to calculate locomotor asymmetry (Bishop, Read, Chavda, & Turner, 2016), two common methods are the Symmetry Index (SI), and Symmetry Angle (SA). The SI measures the percentage difference between two limbs relative to the non-injured or dominant limb, or an average of both limbs. However, in healthy populations there may not be a clear reference limb available and the choice of reference limb can influence the percentage outcome, as the reference limb may not consistently provide the smallest or largest value in the equation for each participant measured (Zifchock, Davis, Higginson, & Royer, 2008). A study by Zifchock et al. (2008) also showed that using an average of both limbs as reference produces a significantly smaller percentage asymmetry than when referenced to one limb (left) (Zifchock et al., 2008). The SA was developed as an alternative to the SI and is calculated by plotting a measure for the right side against a measure for the left side ($X_{right}$,$X_{left}$). A vector line is drawn from this point through the intersection of the *x* and *y* axes, and the angle with respect to the *x*-axis is calculated. Two identical values will create a 45° angle, indicating perfect symmetry. The vector angle can be converted to a percentage and compared to SI results (Zifchock et al., 2008).

Wearable technology such as accelerometers have been suggested as a way to measure meaningful biomechanical asymmetries in human locomotion (Willy, 2018). They have been shown to reliably measure impact loading (Crowell & Davis, 2011), and foot-ground collisions (Lucas-Cuevas, Encarnacion-Martinez, Camacho-Garcia, Llana-Belloch, & Perez-Soriano, 2017). However, it is unclear whether the SI or SA is most suitable to assess these results for inter-limb asymmetry.

The purpose of this paper was to compare the SI with reference to the left side ($SI_{Left}$) and the SI referenced to the average of left and right sides ($SI_{Average}$) with the SA in peak resultant acceleration (PRA) obtained during running.

**METHODS:** Fifteen recreationally active participants (Male $n$ = 9, 23.9 ± 3.6 yrs, 1.8 ± 0.05 m, 78.3 ± 12.0 kg; Female $n$ = 6, 27.3 ± 6.0 yrs, 1.7 ± 0.05 m, 66.3 ± 10.7 kg) volunteered to participate in this study. Participants were eligible to participate if, at the time of recruitment, they were: 1) aged 18-35 years, 2) free of injury, and 3) able to run without restriction. This study was approved by the Macquarie University Human Research Ethics Committee (ethics protocol number: 5201700532). Written informed consent was received from each participant prior to participation.

Participants were required to attend a total of four sessions, separated by a minimum of 24-hours recovery, over the course of a two-week period. The first three sessions were familiarisation sessions that allowed participants to become accustomed to running on a non-motorised treadmill (Force 3, Woodway USA, Inc., Waukesha, WI, USA). All data collection occurred during the final session and all running was performed on the non-motorised treadmill. Each session lasted approximately 20 minutes and was identical for both familiarisation and data collection sessions. Participants performed a standardised warm-up consisting of dynamic stretches and two minutes of steady-state running at 50-60% of self-perceived maximal effort. After a 30-60 second standing rest period, participants ran for 60 seconds at 60% of self-perceived maximal effort and then immediately completed a 15 second sprint at 70% of self-perceived maximal effort. The participant then ran for 60 seconds at 60% self-perceived maximal effort as an active recovery. This sequence was repeated four more times, with the sprint efforts of 80%, 90%, 100%, and 100%, respectively. Running at self-perceived maximal effort is a reliable method of setting running speed on a non-motorised treadmill (Tofari, McLean, Kemp, & Cormack, 2015). The athlete was tethered to a vertical strut at the rear of the treadmill using a belt and cable so that they remained in place while running on the treadmill belt (belt dimensions: 55 cm wide x 173 cm long) (Brown, Brughelli, & Cross, 2016). Two accelerometers (iMeasureU, Auckland, New Zealand) measuring 40 x 28 x 15 mm and weighing 12 g were used to measure accelerations in three axes (x, y and z) at 500 Hz. The two accelerometers were attached to the distal medial tibial malleolus using velcro straps in accordance with manufacturer recommendations.

Analysis of step-by-step acceleration data for each accelerometer was performed using proprietary software (IMU_Step, version 1.0, iMeasureU, Auckland, New Zealand). The variable of interest was the PRA for each step during the 100% sprint. Only the best quality 100% sprint effort for each participant was used for analysis. Data from each 100% sprint were visually inspected to qualitatively determine the sprint with highest data quality. For each participant the selected 100% sprint contained a minimum of 19 steps, and a maximum of 32 steps. Distal tibial PRA provides an indication of lower-limb loading, and increased lower-limb loading is often suggested to increase injury risk (Crowell & Davis, 2011). Using the mean absolute PRA value for the 100% sprint, the $SI_{Left}$ (equation 1), $SI_{Average}$ (equation 2) and SA (equation 3) were calculated (Zifchock et al., 2008):

$$SI_{Left} = \frac{(X_{Left} - X_{Right})}{X_{Left}}\ x\ 100\% \tag{1}$$

$$SI_{Average} = \frac{(X_{Left} - X_{Right})}{avg(X_{Left}, X_{Right})}\ x\ 100\% \tag{2}$$

$$SA = \frac{(45° - \arctan(X_{Left}/X_{Right}))}{90°}\ x\ 100\% \tag{3}$$

Consistent with previous research, the left side was chosen for the SI equation with a single side as a reference value as opposed to the right side (Zifchock et al., 2008).

Paired t-tests were used to assess any systematic bias between $SI_{Left}$ and SA, and between $SI_{Average}$ and SA. Pearson's correlations were calculated to determine the relationship between $SI_{Left}$ and SA, and between $SI_{Average}$ and SA. Consistent with prior research, 15% was used as the threshold for clinically significant asymmetry (Knapik et al., 1991; Zifchock et al., 2006). All analysis was completed using SPSS software (version 23, IBM, Armonk, NY, USA). The alpha level was set at 0.05.

**RESULTS and DISCUSSION:** Symmetry results for all participants, the number of participants presenting with a clinically significant asymmetry for each equation, and the difference between the $SI_{Left}$ and SA, and $SI_{Average}$ and SA symmetry angles are presented in Table 1.

**Table 1: Asymmetry results for each method for all participants.**

| Equation | Asymmetry (%) | No. of participants >15% asymmetry | Difference vs. SA (%) |
|---|---|---|---|
| $SI_{Left}$ | 9.7 ± 7.6 | 5 | 6.6 ± 5.2 |
| $SI_{Average}$ | 9.8 ± 7.6 | 5 | 6.7 ± 5.3 |
| SA | 3.1 ± 2.4 | 0 | Reference |

$SI_{Left}$, Symmetry Index with reference to the left side; $SI_{Average}$, Symmetry Index with reference to the average of left and right sides; SA, Symmetry Angle. Data are presented as mean ± SD.

Significant differences were observed between $SI_{Left}$ and SA ($t(14) = 4.927$, $p < 0.001$) and between $SI_{Average}$ and SA ($t(14) = 4.943$, $p < 0.001$). The SA was positively correlated with $SI_{Left}$ ($r = 0.989$) and $SI_{Average}$ ($r = 1.000$) (Figure 1).

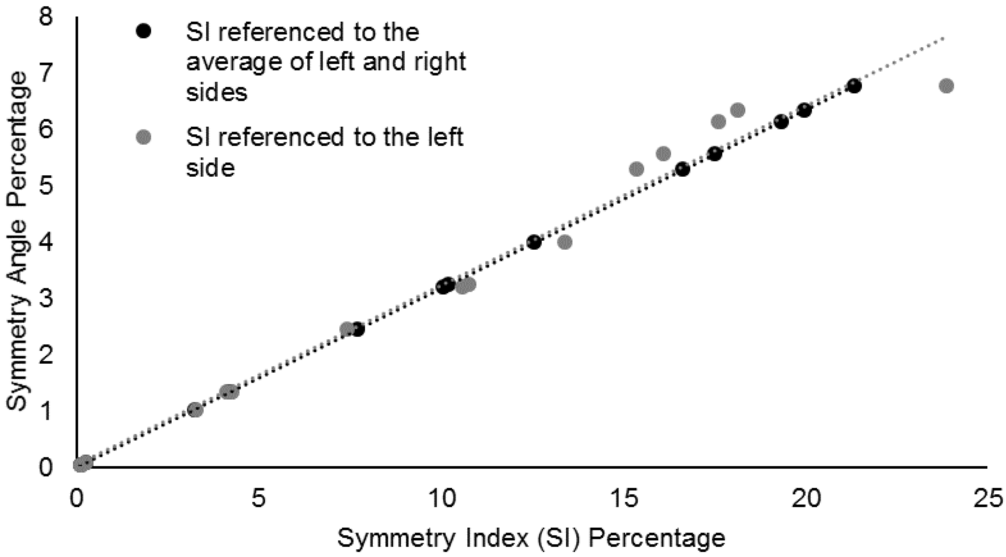


**Figure 1: Relationship between Symmetry Angle and Symmetry Index.**

The results of this study support previous research that suggested the SA produces significantly less asymmetry values than the SI, regardless of whether the left limb or average of both limbs is used as a reference (Błażkiewicz, Wiszomirska, & Wit, 2014). If only the SI equations were used, this study would have found that one third (5/15) of the participants in this study had a clinically significant asymmetry between limbs. However, if the SA was used, no participants would have been found to have inter-limb asymmetry >15%. Clinical significant asymmetries were not expected because participants were only eligible to take part in this study if they were free of injury and able to run without restriction. However, it is possible that each participant may have presented with a level of inherent inter-limb asymmetry, resulting from their training or sporting history, limb dominance, or leg-length discrepancies (Perttunen, Anttila, Södergård, Merikanto, & Komi, 2004; Sadeghi, Allard, & Duhaime, 1997). Indeed, the mean SI of resultant force metrics during sprinting were 3.9-9.6% in a previous study involving healthy adults (Korhonen et al., 2010). As a result, it may not be reasonable to expect that each participant in the present study should be without clinically significant asymmetry between limbs in PRA.

The results of the SA should be interpreted with some caution because a clinically significant asymmetry of >15% may not apply to these results (Zifchock et al., 2008). Knapik et al. (1991), found that inter-limb asymmetries in isokinetic hip and knee strength >15% were a predictor of injury in female collegiate athletes. Since then, a value of 15% asymmetry has been applied to a variety of lower-limb measures. The SA was developed more recently (Zifchock et al., 2008) and it is not known whether a 15% threshold for defining clinically significant asymmetry is still appropriate. Therefore, when using the SA, the percentage chosen as being representative of a clinically significant asymmetry may need to be investigated and modified. Findings from the present study suggest that a threshold of 10% might be more appropriate because SA values were approximately 6-7% lower than SI values.

**CONCLUSION:** This study used accelerometers attached to the distal tibia to measure inter-limb asymmetries in peak acceleration during running. When deriving the percentage difference between limbs, the result depends on the equation used to calculate the inter-limb difference. The SA equation identifies less clinically relevant asymmetries than the SI equation when referenced to the left lower-limb and the average of both lower-limbs. Future research should validate a clinically relevant threshold of asymmetry using the SA because the 15% threshold that is commonly used for the SI may not be appropriate.

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