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A novel method for measuring asymmetry in kinematic and kinetic variables: The Normalized Symmetry Index

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Abstract

Gait and movement asymmetries are important variables for assessing locomotor mechanics in humans and other animals and as a predictor of risk of injury and success of clinical interventions. The four indices used most often to assess symmetry are not well designed for different variable types and perform poorly when presented with cases of high asymmetry or when variables are of low magnitude and are easily influenced by small variation in the signal. The purpose of the present study was to test the performance of these indices on previously unpublished data on ACL-R patients and to propose a new index to resolve some of these limitations. The performance of four currently used indices and a new index—the Normalized Symmetry Index (NSI), which is scaled to the range of variables being tested across multiple trials—were compared using force and angular data on participants who had undergone anterior cruciate ligament reconstruction and healthy controls. The NSI performed well compared to all other indices with all variables and had the additional benefit of returning values that range from 0% (full symmetry) to $\pm 100\%$ (full asymmetry). Therefore, the NSI can serve as a universal index for assessing asymmetry in humans, nonhuman animal models, and in a clinical context for assessing risk for injury and clinical outcomes.

Keywords

Symmetry; Kinetics; Kinematics; Pathology; Injury; Prevention

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Conflicts of Interest Statement

The authors have no conflicts of interest relevant to this study.

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Introduction

Asymmetry in mechanical behavior between right and left limbs during walking, running, jump landing, and other athletic activities is often used to assess athletic skills, efficacy of surgical interventions, and to evaluate potential risks of re-injury, and has been used extensively in gait analysis for more than 5 decades (Blazkiewicz et al., 2014; Drillis, 1958; Jafarnejadgero et al., 2018; Ounpuu and Winter, 1989; Patterson et al., 2010; Robinson et al., 1987; Sadeghi et al., 2000; Vagenas and Hoshizaki, 1992). Further, asymmetry measures can be used to measure limp or lameness in humans (Drillis, 1958; Patterson et al., 2010) and in nonhuman animals in clinical, agricultural, and zoological settings (Gillette and Angle, 2008; Robilliard et al., 2007). At present, researchers most commonly use one of four symmetry indices to evaluate movement: the Symmetry Index (SI) (Robinson et al., 1987), the Ratio Index (RI) (Ganguli et al., 1974), Gait Asymmetry (GA) (Plotnik et al., 2005) and Symmetry Angle (SA) (Zifchock et al., 2008), though there are additional less commonly used indices as well (Cabral et al., 2016; Nigg et al., 2013; Vagenas and Hoshizaki, 1992). Despite their apparent utility, the application of symmetry indices in clinical settings, sports settings, and in biomechanical studies of humans and other animals has been challenging for a number of interconnected reasons. For example, there is no consensus on how symmetry is most effectively measured, especially as multiple variables are often used, including forces, distances, angles, and moments. Although there are a number of indices described in the literature, all of them have limitations in handling these different variable types.

Several recent studies have explored the behavior of some commonly used indices, finding that there is often strong associations between them, but also disparate results depending on what variables are tested (Blazkiewicz et al., 2014; Jafarnejadgero et al., 2018; Patterson et al., 2010; Sadeghi et al., 2000). The SI, RI, GA, and SA are univariate indices with shortcomings that have limited their utility in specific settings. Blazkiewicz et al. (2014) recently provided a comprehensive review that addresses this issue by comparing multiple indices (RI, SI, GA, SA) and variables in an attempt to determine the most relevant index for specific datasets. A high degree of correlation between the SI, RI, GA and the SA has been found, leading to the suggestion that they may be used interchangeably (Blazkiewicz et al., 2014), but as noted by Bland and Altman (Altman and Bland, 1983; Bland and Altman, 1986), a high correlation coefficient is an inappropriate measure of the agreement of two techniques.

Here we test four symmetry indices and propose a new approach—a normalized symmetry index (NSI) that is similar to the index proposed by Vagenas and Hoshizaki (1992), which relies on the range of variation within the sample to scale the results of the index. The NSI should allow comparisons of symmetry across a range of data by returning a value of zero when there is perfect symmetry and a maximum value of 100 (or –100) when there is “perfect asymmetry” (i.e., the two limbs generate values that span the entire range of possible values that the variable can have; with one at one end of the range and the other at the other end).

Rather than simply test this on artificial data, we chose to test the indices using real and previously unpublished data on patients who have undergone anterior cruciate ligament

reconstruction surgery (ACL-R). We chose this type of dataset because ACL-R is a common surgical procedure and one to which symmetry measures are often applied to determine surgical outcome and time of return to sport (Barber et al., 1992; Benjaminse et al., 2018; Biggs et al., 2009; Capin et al., 2017; Capin et al., 2019; Dai et al., 2012, 2014; DeMaio et al., 1992; Nagai et al., 2019; Pottkotter et al., 2018; Shelbourne and Klotz, 2006; Zwolski et al., 2016). In addition, limb mechanics data offers different variable types including peak forces, extension moments, range of motion, and angles that provided different ranges of variation and units to robustly test all indices with the variables commonly used. In addition, this dataset allowed us to analyze symmetry on a trial by trial basis (compared sides within a trial) rather than the average limb behavior, a pattern used often in animal studies out of necessity, but one that can be avoided in studies of human locomotion. Throughout this paper we take this trial by trial approach by calculating a symmetry value for each trial and reporting the average results.

Methods

To examine the efficacy of four standard indices and the NSI, a population of anterior cruciate ligament reconstruction (ACL-R) patients was recruited and asymmetry during a stop jump task was examined. Following an ACL-R, it has been reported that patients show decreased loading symmetry between limbs during landing tasks (Butler et al., 2014; Dai et al., 2012, 2014; Paterno et al., 2007; Paterno et al., 2012, 2014). Asymmetries in the knee extension moment and in frontal plane range of motion have been associated with an increased risk of sustaining a second ACL tear following return to sports (Paterno et al., 2012, 2014).

Twenty-two young adult athletes who had undergone ACL-R were recruited at 26.3 ± 6.3 weeks since ACL-R (approximately 6.6 ± 1.6 months). This included 13 male participants and 9 female participants. The average age was 17.3 ± 2.2 years, average height 1.75 ± 0.11 m, and average weight was 72.4 ± 14.5 kg. All surgical patients underwent an ACL tibial tunnel-independent reconstruction with a hamstring graft and were released to participate by the treating orthopaedic surgeon, who was comfortable with the participant running and jumping in a controlled environment. Twenty-two control participants with no known injury were matched to the ACL-R participants who completed this study. This included 13 male participants and 9 female participants. The average of the control group was 22.3 ± 2.7 years; average height was 1.73 ± 0.11 m; and average weight was 70.7 ± 12.6 kg. All participants signed an institutional review board approved assent or consent form prior to testing.

Three-dimensional video and force data were collected on all participants during a stop-jump task. Forty-six retro-reflective markers were placed on specific lower extremity landmarks by a single researcher as previously described (Butler et al., 2014; Dai et al., 2012, 2014). A 10-camera motion capture system collected three-dimensional data at 120 Hz (Qualysis, Goteborg, Sweden). Ground reaction forces (GRF) were measured with two embedded force plates collecting at 2400 Hz (AMTI, Watertown, MA). Each participant performed five vertical stop-jump tasks as previously described (Butler et al., 2014; Dai et al., 2012, 2014), while bilateral lower extremity kinematic and kinetic data were collected.

Participants were told to approach as quickly as possible and to jump as high as they felt was safely possible, and no instructions about landing position or technique were provided.

The three-dimensional data and GRFs were filtered with a low-pass Butterworth digital filter at 12 Hz and 100 Hz, respectively. Time series curves were generated with Visual 3D software (C-Motion, Bethesda, Maryland, USA) and Matlab (MathWorks, Natick, MA) was used to extract peak vertical ground reaction force (peak vGRF), peak knee extension moment, frontal plane knee range of motion (KROM), and peak knee valgus angle. These variables examined were selected to provide a range of data types and magnitudes of potential asymmetry. All variables are commonly used during movement assessment in human performance labs and in clinical settings (Butler et al., 2014; Dai et al., 2012, 2014; Paterno et al., 2007; Paterno et al., 2012). Peak vGRF is a kinetic measure of limb loading and has large magnitude values, which during landing is approximately 4.5 times bodyweight (McNair and Prapavessis, 1999). Peak knee extension moment also has high magnitude values (an average of 2.2 Nm/kg in the present study), though lower than the peak vGRF. Frontal plane KROM is derived from angular data and has smaller magnitude values, which were 10.9 degrees on average in this study. Peak knee valgus angle is a simple angular measure with small values that averaged 5.6 degrees in this dataset.

The four commonly used symmetry indices are tested and defined below. Each of these indices can be calculated on a trial by trial basis or as an average across trials, which have both been done previously (Blazkiewicz et al., 2014; Cabral et al., 2016; Patterson et al., 2010; Zifchock et al., 2008). In describing them, all measures are computed for a variable of interest X , for the two limbs denoted by X_S and X_{NS} for “surgical” and “non-surgical” limb, respectively. For healthy patients, the non-dominant limb was assigned as the “surgical” and the dominant as the “non-surgical” limb.

- a. Ratio Index (RI) (Ganguli et al., 1974): The Ratio Index uses the ratio of the values for the two limbs as the index of symmetry. For a variable X , it is defined as $RI = \left(1 - \frac{X_S}{X_{NS}}\right) \cdot 100$. RI = 0% indicates full symmetry, while RI > 100% indicates asymmetry. Values can exceed 100% and are not bounded. A negative value is possible if $X_{NS} < X_S$.
- b. Gait Asymmetry (GA) (Plotnik et al., 2005): The Gait Asymmetry index is simply a logarithmic transform of the ratio index. It is defined as $GA = \ln\left(\frac{X_{NS}}{X_S}\right) \cdot 100$. Again, GA=0% indicates full symmetry while GA >100% indicates full asymmetry. Values can exceed 100% and are not bounded. A negative value is possible if $X_{NS} < X_S$. Note that the GA can only be defined when the ratio between X_{NS} and X_S is positive and hence is not easily used when the variable to be measured can take both positive and negative values (flexion and extension in typical movement assessments, for instance).
- c. Symmetry Index (SI) (Robinson et al., 1987): The Symmetry Index is the most commonly used index and is a generalization of the RI, where the denominator is taken to be the average of the absolute values for both limbs. There are

alternative definitions where either limb is taken as the reference. In such cases, the SI simply reduces to the RI. The standard SI is defined as

$$SI = \frac{X_{NS} - X_S}{0.5(|X_S| + |X_{NS}|)} \cdot 100, \text{ Again, SI=0\% indicates full symmetry, whereas SI >}$$

100% indicates full asymmetry. As in the above, values can exceed 100% and are not bounded. A negative value indicates that $X_{NS} < X_S$. Because of this, in some applications, the absolute value of the SI is reported rather than the SI itself.

- d. Symmetry Angle (SA) (Zifchock et al., 2008): The Symmetry Angle is a fairly newly developed index that captures symmetry in angular data. It is defined as

$$SA = \frac{45^\circ - \arctan\left(\frac{X_S}{X_{NS}}\right)}{90^\circ} \cdot 100. \text{ SA = 0\% indicates full symmetry and SA > 100\%}$$

indicates full asymmetry.

Each of these indices is useful in their own way and they all have the property of having a value 0 for full symmetry, which is said to occur when $X_S = X_{NS}$. These indices also have the property of all being related to the ratio between the X_S and X_{NS} in different ways. But they also all return non-linear results and perform asymptotically as values increase. Moreover, many of them have no upper bound for asymmetry therefore raising the question of what is considered maximum asymmetry.

To potentially address these limitations, we propose an index that retains the advantages of the SI, but that should return linear values, is normalized to variable magnitude, and function as a bounded symmetry index. This method theoretically can be used to relate the symmetries in different variables comparably. The index proposed here builds on the index proposed by Vagenas and Hoshizaki (1992), where the symmetry score is equal to

$$\frac{X_{left} - X_{right}}{\max(X_{left}, X_{right})} \cdot 100. \text{ Their index and the one we propose relies on the range of variation}$$

within the variable being tested to normalize the difference score (in the numerator) (Vagenas and Hoshizaki, 1992). In the current index, detailed below, the maximum range of values for the dataset (irrespective of limb) is used as the normalizing variable. It is important to note that this normalizing variable is derived from multiple trials (at least 3) and not from a single trial. This accounts for the magnitude of variation in the variables used and returns values between 0%, or full symmetry with both limbs having the same value, and $\pm 100\%$, or full asymmetry where each limb generates results that span the entire range of possible values that the variable can have, with one limb showing values at one end of the range and the other limb at the other end. The Normalized Symmetry Index (NSI), therefore, is defined as:

$$NSI = \frac{X_{NS,t} - X_{S,t}}{\max_{t=1:n}(\max(0, X_{NS,t}, X_{S,t})) - \min_{t=1:n}(\min(0, X_{NS,t}, X_{S,t}))} \cdot 100$$

In this formula, the numerator represents the difference between the surgical and non-surgical limbs for a single trial, denoted by the subscript t. The denominator represents the

maximum and minimum values for the particular measure across n trials, where n is a minimum of three trials. If all values are positive, 0 will be used as the minimum value. The NSI should be calculated for each trial and then averaged to get a symmetry score for the participant. If only one trial can be obtained, the NSI should only be used when all values are positive.

To compare the symmetry measures, we calculated peak vGRF, peak knee extension moment, frontal plane ROM, and peak knee valgus angle symmetry using the ratio index, gait asymmetry index, symmetry index, symmetry angle, and normalized symmetry index. This was done for each participant, and the mean, standard deviation, median, minimum, and maximum values for each variable and each index was found for the ACL-R and control groups. To look at measures of “agreement” when comparing different symmetry measurement indices we used the analyses proposed by Bland and Altman to statistically test the behavior between indices (Altman and Bland, 1983; Bland and Altman, 1986). This approach includes a statistical test of similarities between indices and can be expressed as p -values. In the results, we present the Bland-Altman plots and the associated p -values (Altman and Bland, 1983; Bland and Altman, 1986) of those comparisons.

Results

General results for the four standard indices

All four indices diverge quite a bit when we move from values indicating symmetry to values indicating asymmetry (Figure 1). Bland-Altman plots and their associated p -values show high levels of agreement between the SI and the other indices in the control group for the common human movement variable of peak vGRF (Figure 2).

Results for individual indices

There is a trend towards disagreement between the different indices as symmetry decreases and in comparing ACL-R patients with controls. For example, Bland-Altman plots for the frontal plane ROM, where asymmetry is common, highlight this problem (Figure 3) and show that RI and GA tend to be unstable and can take on large values under certain conditions. As seen from the analysis in Tables 1–4, the RI can sometimes generate large, unbounded values and hence is not universally recommended. This finding shows both the weakness of RI and GA in many cases and the lack of utility in comparisons using such plots with values of low symmetry. Figure 4 presents heat maps of the behavior of each index over a wide range of variables. Compared to the NSI (top row), the RI, GA, SI, and SA (shown in the bottom rows) all behave poorly, showing discontinuous values and many non-numerical values across a wide range of inputs.

The behavior of the Normalized Symmetry Index (NSI)

The NSI indicates full symmetry with a value of zero and has a maximum absolute value of 100%, which is defined here as full asymmetry. When calculated with one trial, the NSI behaves poorly (Figure 4, top left). It saturates at high values over a wide range of inputs and produces non-numerical results. The saturation means that ratios that should be different do not produce different values. But when calculated using multiple trials, the NSI changes

continuously (Figure 4, top right) and is highly correlated with the other indices at values close to 0. Tables 1–4 and figures 1–4 demonstrate how the NSI performs relative to the other indices for our dataset. The NSI behaved well under all conditions and all types of variables. It was stable, linear, and returned consistent results for all tests. The NSI did not produce extreme results (Tables 1–4), as it stayed within the bounds of $0 - \pm 100$, and showed good agreement in Bland-Altman plots (Figures 2–3), with the majority of the data points remaining inside the 95% limits of agreement. Because it is stable over a wide range of variables and includes the full range of values, the NSI generated lower ranges of variation (Figure 1–4, Tables 1–4).

Discussion

Assessing gait symmetry is an important part of mechanical studies of locomotion in humans and other animals. Declines in movement symmetry appear to be a valuable measure of athletic performance, overall health, and as a robust predictor of injury, outcome measure, and a predictor of re-injury (Blazkiewicz et al., 2014; Drillis, 1958; Jafarnezhadgero et al., 2018; Ounpuu and Winter, 1989; Patterson et al., 2010; Robinson et al., 1987; Sadeghi et al., 2000; Vagenas and Hoshizaki, 1992). Yet there exists no consensus on which of the many available indices is the most effective and consistent way to assess limb symmetry. At present, there are four indices that are readily used (Blazkiewicz et al., 2014; Patterson et al., 2010). All of these have different mathematical properties and behave differently when presented with different types of variables (Figures 1–4). For variables that are always positive and have relatively high magnitude such as the peak vGRF, there is no practical difference between any of these indices. There is also substantial agreement for most variable types when working with participants who are fairly symmetric. This is a key observation in Blazkiewicz et al and we confirm it in Tables 1–4 and Figures 1–2 (Blazkiewicz et al., 2014). However, the values of the asymmetry indices for Peak Valgus Angle or for those participants with significant asymmetry reveal substantial differences between the behaviors of the different asymmetry indices (Figures 1 and 3). There is a clear need for a universal asymmetry index for complex datasets involving a whole range of asymmetry across different kinetic and kinematic variables.

This study tested these indices with force and angular data on participants who had undergone an ACL-R and healthy controls. All of the four standard indices perform relatively poorly when presented with cases of high asymmetry or when variables are of low magnitude and all of them were easily influenced by small variation in signal or errors. For example, the GA is not defined for variables that take both negative and positive values and hence it is not recommended as a universal index. The RI is the basic template on which the other indices are based, but it has the drawback of being overly sensitive to small values in the denominator. Additionally, while the SA functions most effectively for computing angular symmetry, it does not perform well with other variable types.

The SI combines many of the robust and valuable properties of the other indices. When defined as the ratio of the difference between the two limbs to the average value between the two limbs, it is bounded between -200% and 200% . However, it is interesting to analyze the behavior of the SI as symmetry decreases between two limbs. The absolute value of SI takes

a value of 100% when $X_S = 3X_{NS}$ or vice versa, which indicates quite a large between-limb asymmetry. However, the maximum (absolute) SI value of 200% occurs discontinuously when X_S are of opposite sign. The difference in magnitudes of X , that crucially determines the extent of asymmetry for other values of SI becomes obscured when the SI returns high values.

To remedy the poor performance of the standard indices in cases of high asymmetry and with variables of low magnitudes, we tested an index that builds on the symmetry index, but is modified so that the level of symmetry is scaled to the range of amplitude variation within the sample based on data from multiple rather than single trials. This index — the Normalized Symmetry Index (NSI) — performed well with all variables at low levels of symmetry. It returned continuous values from 0% (full symmetry) to $\pm 100\%$ (full asymmetry). This is calculated on a trial by trial basis in order to most effectively assess the differences between limbs and the interplay between them.

Based on the ability of the NSI to perform well at low levels of symmetry and given that it is bounded between 0% and $\pm 100\%$, the NSI can be used easily in any setting and can serve as a universal index for assessing symmetry in a clinical context, though it should be noted that, like all other indices, the NSI performs least well when one value is negative and very different from the other. The NSI will allow for a standardized index across all joints and therefore should be able to be used to assess injury risk and clinical outcomes.

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Figure 1:

Box plots representing the values of all symmetry indices (RI, GA, SI, SA, NSI) for vGRF, peak knee extension moment, frontal plane ROM, and peak valgus angle in both control and ACL populations.

Figure 2:

Bland-Altman plots showing agreement between SI and other symmetry indices for the control participants for and peak vGRF. The circles correspond to the difference between the symmetry indices plotted against the average value of the two symmetry indices for each subject, while the horizontal lines show the mean and 95% confidence intervals for the difference between the respective indices. The plot shows that the difference between the indices for any subject is largely within the confidence limits although the general patterns show that the indices tend to disagree widely when symmetry decreases (the X-axis value increases).

Figure 3:

Bland-Altman plots showing agreement between SI and other symmetry indices for ACLR participants for frontal plane ROM. The circles correspond to the difference between the symmetry indices plotted against the average value of the two symmetry indices for each subject, while the horizontal lines show the mean and 95% confidence intervals for the difference between the respective indices. The plot shows that the difference between the indices for any subject is largely within the confidence limits although the general patterns show that the indices tend to disagree widely when symmetry decreases (the X-axis value increases).

Figure 4:

Heat maps showing how the symmetry indices behave when calculated with a single trial and with multiple trials, with the top row representing the NSI. The map on the top left shows that when calculated with one trial, the NSI does not provide continuous values when X_{NS} or X_S is negative. These values saturate at high values of 100 or -100 over a wide range of inputs. It is also the case that when one trial is used, some values cannot be calculated. However, when calculated with multiple trials, the NSI can take the full range of values for any combination of X_{NS} and X_S , as shown on the top right. Although there still some saturation on the extremes, this is over an appropriate range of inputs. The remaining four rows show other standard indices calculated in a similar fashion. All other indices perform poorly by saturating and providing non-continuous results, as well as non-numerical values, compared to the NSI.

Table 1:

All five indices compared using the peak vertical ground reaction force in ACL reconstruction patients and controls. RI = ratio index, GA = gait asymmetry index, SI = symmetry index, SA = symmetry angle, NSI = normalized symmetry index. The mean, median and the absolute minimum and maximum values are shown. The mean and the median symmetry indices are computed by taking the average values of the variables for a participant across multiple trials and computing the symmetry index on this average value. The alternative computation of finding trial-by-trial symmetry and then finding the mean, median, minimum and maximum of the trial-by-trial symmetry for each individual yields similar results.

Variable	Symmetry Index	Group	Mean	Standard Deviation	Median	Min (abs)	Max (abs)
Peak vGRF	RI	ACLR	10.80	14.51	12.92	0.69	35.98
Peak vGRF	RI	Control	-0.28	15.33	1.50	0.23	38.99
Peak vGRF	GA	ACLR	12.76	16.89	13.83	0.69	44.59
Peak vGRF	GA	Control	0.82	15.07	1.51	0.23	32.92
Peak vGRF	SI	ACLR	12.64	16.70	13.81	0.69	43.87
Peak vGRF	SI	Control	0.82	15.00	1.51	0.23	32.63
Peak vGRF	SA	ACLR	3.99	5.26	4.39	0.22	13.75
Peak vGRF	SA	Control	0.26	4.75	0.48	0.07	10.29
Peak vGRF	NSI	ACLR	8.39	10.98	10.12	0.56	28.61
Peak vGRF	NSI	Control	0.56	11.50	1.13	0.20	24.86

Table 2:

All five indices compared using peak extension moment in ACL reconstruction patients and controls. RI = ratio index, GA = gait asymmetry index, SI = symmetry index, SA = symmetry angle, NSI = normalized symmetry index. The mean, median and the absolute minimum and maximum values are shown. The mean and the median symmetry indices are computed by taking the average values of the variables for a participant across multiple trials and computing the symmetry index on this average value. The alternative computation of finding trial-by-trial symmetry and then finding the mean, median, minimum and maximum of the trial-by-trial symmetry for each individual yields similar results.

Variable	Symmetry Index	Group	Mean	Standard Deviation	Median	Min (abs)	Max (abs)
Peak Knee Extension Moment	RI	ACLR	22.99	26.17	27.53	0.28	58.92
Peak Knee Extension Moment	RI	Control	3.89	9.84	3.12	0.12	28.17
Peak Knee Extension Moment	GA	ACLR	31.45	33.33	32.21	0.28	88.97
Peak Knee Extension Moment	GA	Control	4.50	10.76	3.17	0.12	33.08
Peak Knee Extension Moment	SI	ACLR	30.44	32.04	31.93	0.28	83.53
Peak Knee Extension Moment	SI	Control	4.48	10.71	3.17	0.12	32.78
Peak Knee Extension Moment	SA	ACLR	9.41	9.85	10.08	0.09	25.19
Peak Knee Extension Moment	SA	Control	1.42	3.39	1.01	0.04	10.34
Peak Knee Extension Moment	NSI	ACLR	20.49	20.93	24.09	0.25	51.27
Peak Knee Extension Moment	NSI	Control	3.38	8.34	2.81	0.11	23.69

Table 3:

All five indices compared using frontal plane range of motion in ACL reconstruction patients and controls. RI = ratio index, GA = gait asymmetry index, SI = symmetry index, SA = symmetry angle, NSI = normalized symmetry index. The mean, median and the absolute minimum and maximum values are shown. The mean and the median symmetry indices are computed by taking the average values of the variables for a participant across multiple trials and computing the symmetry index on this average value. The alternative computation of finding trial-by-trial symmetry and then finding the mean, median, minimum and maximum of the trial-by-trial symmetry for each individual yields similar results.

Variable	Symmetry Index	Group	Mean	Standard Deviation	Median	Min (abs)	Max (abs)
Frontal Plane ROM	RI	ACLR	-23.76	58.19	-10.07	1.25	165.24
Frontal Plane ROM	RI	Control	-1.91	47.49	12.38	0.33	115.43
Frontal Plane ROM	GA	ACLR	-11.07	46.43	-9.57	1.26	97.55
Frontal Plane ROM	GA	Control	6.72	40.77	13.25	0.32	76.74
Frontal Plane ROM	SI	ACLR	-10.47	44.75	-9.57	1.26	90.48
Frontal Plane ROM	SI	Control	6.81	39.56	13.22	0.32	73.19
Frontal Plane ROM	SA	ACLR	-3.18	13.80	-3.04	0.40	27.05
Frontal Plane ROM	SA	Control	2.19	12.25	4.20	0.10	22.33
Frontal Plane ROM	NSI	ACLR	-4.97	24.01	-5.18	0.80	48.90
Frontal Plane ROM	NSI	Control	4.34	23.22	8.88	0.24	41.61

Table 4:

All five indices compared using peak valgus angle in ACL reconstruction patients and controls. RI = ratio index, GA = gait asymmetry index, SI = symmetry index, SA = symmetry angle, NSI = normalized symmetry index. The mean, median and the absolute minimum and maximum values are shown. The mean and the median symmetry indices are computed by taking the average values of the variables for a participant across multiple trials and computing the symmetry index on this average value. The alternative computation of finding trial-by-trial symmetry and then finding the mean, median, minimum and maximum of the trial-by-trial symmetry for each individual yields similar results.

Variable	Symmetry Index	Group	Mean	Standard Deviation	Median	Min (abs)	Max (abs)
Peak Valgus Angle	RI	ACLR	109.02	466.26	-8.98	3.71	2044.48
Peak Valgus Angle	RI	Control	11.51	126.08	20.11	3.48	265.90
Peak Valgus Angle	GA	ACLR	-3.28	99.25	-20.59	3.64	244.38
Peak Valgus Angle	GA	Control	-5.54	79.74	-3.42	3.42	190.61
Peak Valgus Angle	SI	ACLR	18.87	111.15	20.51	3.64	200.00
Peak Valgus Angle	SI	Control	-29.14	111.45	-16.15	3.42	200.00
Peak Valgus Angle	SA	ACLR	20.84	56.39	-2.71	1.16	146.73
Peak Valgus Angle	SA	Control	18.44	43.46	7.10	1.09	111.23
Peak Valgus Angle	NSI	ACLR	5.50	21.43	4.80	1.01	42.64
Peak Valgus Angle	NSI	Control	-4.07	26.04	-6.81	0.34	62.39