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Persistent Gait Asymmetry After Lower-Limb Injury: Comparing Raw Spatio-Temporal Measures and Symmetry Indices in a Mixed Outpatient Rehabilitation Cohort

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ABSTRACT

Background: Persistent gait asymmetry following lower-extremity injury is a clinically significant but frequently under-detected rehabilitation outcome. Raw spatio-temporal parameters may lack sensitivity for subtle inter-limb differences, whereas symmetry indices (SI) offer a dimensionless, ratio-based measure of residual mechanical asymmetry. This study compared raw spatio-temporal parameters and symmetry indices in their ability to detect post-rehabilitation gait asymmetry across clinically relevant subgroups.

Methods: Sixty-five adults with unilateral lower-extremity injuries (conservative n=33; surgical n=32; knee n=45, ankle n=16, hip n=4) were assessed after completing physiotherapy. Spatio-temporal gait parameters were recorded bilaterally at self-selected speed using a validated two-dimensional video-based workflow (Kinovea; ICC >0.95). Robinson symmetry index (SI%) was computed for each parameter; SI >10% indicated clinically meaningful asymmetry. Subgroup comparisons by management type, injury site, and recovery duration (<6 vs. ≥6 months post-rehabilitation) used non-parametric tests with Holm-Bonferroni correction.

Results: Only step length differed significantly between limbs on raw comparison (51.2±10.0 cm vs 52.8±13.9 cm; p=0.028). Symmetry indices revealed additional clinically meaningful differences: step-length SI was greater in the surgical group (16.0±21.0% vs 10.6±21.0%; p=0.018), and single-limb support time SI was higher in participants assessed within six months of discharge (27.5±39.7% vs 13.2±18.2%; p=0.048). No significant SI differences were found across injury sites (p>0.32).

Conclusion: To our knowledge, this is the first study to compare raw spatio-temporal measures with symmetry indices across a mixed cohort of conservatively and surgically managed lower-extremity injuries using a validated two-dimensional video workflow in an Indian outpatient physiotherapy setting. Symmetry indices provide superior detection of residual gait asymmetry compared to raw measures, supporting their routine integration — using a pragmatic >10% threshold — into discharge decisions and targeted rehabilitation in resource-limited settings.

Keywords: gait asymmetry, symmetry index, spatio-temporal parameters, lower extremity rehabilitation, Kinovea, post-rehabilitation outcomes.

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INTRODUCTION

Lower-extremity injuries are among the most prevalent musculoskeletal conditions encountered in outpatient physiotherapy, contributing substantially to functional disability and prolonged rehabilitation burden. In Indian tertiary care centers, lower-extremity trauma accounts for more than 40% of musculoskeletal admissions [1, 2]. Despite completion of standard rehabilitation, a growing body of evidence demonstrates that gait mechanics do not fully normalize at the point of discharge [3, 4].

The biomechanical consequences of unilateral lower-extremity injuries include persistent alterations in spatial parameters such as step length and temporal parameters such as single-limb support time. These abnormalities arise from complex interactions among residual pain inhibition, neuromuscular control deficits, and protective motor strategies that frequently outlast tissue healing [5]. Compensatory gait patterns — reduced anterior-posterior limb excursion, hip hiking, circumduction, and prolonged double-support — are commonly adopted and may persist well beyond clinical discharge [6].

Emerging evidence confirms that spatio-temporal gait asymmetries persist despite standard rehabilitation across multiple lower-extremity conditions. Following anterior cruciate ligament reconstruction (ACLR), inter-limb asymmetries remain detectable at six months and beyond, even in patients who meet conventional return-to-sport criteria [7, 8]. After ankle fracture, systematic reviews report reduced walking speed, shorter step length, and prolonged double-support time detectable up to twelve months post-injury [9, 10]. After hip or knee arthroplasty, instrumented gait analyses reveal long-term deviations in cadence and step-length distribution persisting years post-surgery [11, 12]. Hušek et al. (2025) [13] further confirmed that spatiotemporal gait deficits persist regardless of the type of surgical reconstruction employed, indicating these impairments are not merely a product of injury severity.

Standard clinical practice compares raw spatio-temporal values between limbs. However, raw comparisons may fail to detect subtle but clinically meaningful asymmetries, particularly when patients adopt bilateral adaptations — such as globally slowed walking speed — that mask absolute inter-limb differences [14, 15]. Symmetry indices (SI) address this limitation by expressing inter-limb differences relative to the mean of both limbs, yielding dimensionless percentage values independent of walking speed, body size, or measurement units [16, 17]. The Robinson-type SI is among the most widely validated formulations, and recent work by Streamer et al. (2025) [18] supports a 10-15% threshold for clinically meaningful asymmetry. Prior SI studies have demonstrated utility across stroke, ACLR, arthroplasty, and amputation cohorts [7, 9, 11].

Despite this evidence, three specific gaps remain unaddressed. First, existing SI studies are overwhelmingly condition-specific, focusing on a single pathology rather than mixed real-world outpatient cohorts that include multiple injury sites and both conservative and surgical management simultaneously. Second, the vast majority rely on three-dimensional motion capture unavailable in most outpatient settings globally and in Indian tertiary care centres specifically [19, 20]. Two-dimensional video-based analysis using Kinovea has demonstrated good-to-excellent reliability for spatio-temporal parameters [19, 20], yet no study has examined SI values from this workflow in a post-rehabilitation musculoskeletal cohort. Third, direct evidence on how step-length SI and single-limb support time SI evolve between early and late post-rehabilitation phases in a mixed injury cohort is lacking.

Therefore, this study examined residual gait asymmetry in adults who had completed rehabilitation for unilateral hip, knee, or ankle injuries, using a pragmatic Kinovea-based two-dimensional workflow. We compared raw spatio-temporal parameters with symmetry indices in detecting clinically meaningful asymmetry (SI >10%), and evaluated SI differences across management type, injury site, and recovery duration.

METHODOLOGY

Study Design

This prospective, cross-sectional observational study was conducted in the Physiotherapy Outpatient Department of a tertiary care teaching hospital in Mysuru, India. Reporting follows STROBE guidelines. Ethics approval was obtained from the Institutional Ethics Committee. All participants provided written informed consent prior to participation.

Participants

Inclusion criteria: adults aged 18-65 years; unilateral lower-extremity injury; ≥3 weeks weight-bearing; independent ambulation without assistive devices. Exclusion criteria: bilateral lower-extremity injuries; neurological or congenital gait disorders; current use of walking aids; inability to complete the protocol. Participants were recruited consecutively via convenience sampling.

Sample Size

An a priori power calculation (G*Power 3.1; one-sample Wilcoxon signed-rank test; two-tailed $\alpha=0.05$, power=0.80, d=0.30) indicated a minimum of n=65. The target sample was achieved with complete data from all 65 participants.

Participant Characteristics

Sixty-five adults (45 males, 20 females) completed testing (mean age 29 ± 12 years; height 170.6 ± 10.4 cm; weight 69.2 ± 13.7 kg; BMI 23.9 ± 5.2 kg/m^2). Injury distribution: knee (n=45), ankle (n=16), hip (n=4). Management: conservative (n=33), surgical (n=32). Assessment timing post-rehabilitation: <6 months (n=35) or ≥6 months (n=30). No missing data (Table 1).

Instrumentation and Procedure

Participants walked at self-selected comfortable speed along an 8-m, non-slip, well-lit indoor walkway. Self-selected speed was chosen to maximize ecological validity and reflect typical outpatient conditions where velocity standardization is often not feasible. A central 0.89-m segment was pre-calibrated with a steel measuring tape. Following one familiarisation trial, participants completed three recorded trials with approximately two minutes' rest between trials.

A digital video camera (1080p, 30 fps) was mounted at greater trochanter height, aligned perpendicular to the direction of progression, and positioned 3.05 m from the walkway midpoint to minimize parallax error. Videos were analyzed using Kinovea (version 0.9.5), a low-cost two-dimensional motion-analysis program with demonstrated intra- and inter-rater reliability (ICC >0.95) for spatio-temporal gait parameters compared with laboratory-based systems [19, 20]. Frame-by-frame manual digitization identified gait events. The mean of three valid trials per participant was used for all analyses.

Outcome Measures

Six spatio-temporal parameters were extracted separately for affected and unaffected limbs: (1) step length (cm); (2) stride length (cm); (3) step time (s); (4) stride time (s); (5) single-limb support (SLS) time (s); (6) swing time (s).

Symmetry Index

Inter-limb asymmetry was quantified using the Robinson Symmetry Index[16]:

SI (%) = [(Affected – Unaffected) / ((Affected + Unaffected) / 2)] × 100

SI >10% was interpreted as clinically meaningful asymmetry, consistent with established thresholds [16, 18].

Statistical Analysis

Analyses were performed using Python 3.9 (SciPy v1.9.3; Pingouin v0.5.3). Shapiro-Wilk tests assessed normality. Given predominantly non-normal distributions ($p \leq 0.001$ for most variables), non-parametric methods were applied: Wilcoxon signed-rank test for within-participant affected vs. unaffected comparisons; Mann-Whitney U for two-group comparisons (management type, recovery duration); Kruskal-Wallis with Dunn's post hoc for three-group comparisons (injury site). Effect sizes: rank-biserial correlation (r) for two-group tests; epsilon-squared (ε^2) for multi-group tests. Holm-Bonferroni correction controlled family-wise error. α=0.05. Continuous variables: mean ± SD.

RESULTS

Participant Characteristics and Data Completeness

All 65 participants completed testing with no missing data (Table 1). Shapiro-Wilk tests indicated predominantly non-normal distributions across all parameters ($p \leq 0.001$ for most variables), supporting non-parametric analyses (Tables 2 and 3).

Table 1: Demographic characteristics and sample distribution (n=65). Values are mean (SD).

Participant Characteristic	Mean (SD)
Age (years)	29 (12)
Height (cm)	170.6 (10.4)
Weight (kg)	69.2 (13.7)
BMI (kg/m²)	23.9 (5.2)

Note. SD = standard deviation; BMI = body mass index. Injury: knee n=45, ankle n=16, hip n=4. Management: conservative n=33, surgical n=32. Assessment timing: <6 months n=35, ≥6 months n=30.

Table 2: Shapiro-Wilk normality test results for Spatio-temporal parameters (n=65).

Parameter	Affected (p)	Unaffected (p)
Step length	0.033*	<0.001*
Stride length	0.002*	<0.001*
Step time	<0.001*	<0.001*
Stride time	<0.001*	<0.001*
SLS time	<0.001*	<0.001*
Swing time	<0.001*	0.159

*Note. * $p < 0.05$ indicates non-normal distribution. SLS = single-limb support. Non-parametric tests used throughout.*

Table 3: Shapiro-Wilk normality test results for symmetry indices across subgroups.

SI Parameter	Conservative (p)	Surgical (p)	Hip (p)	Knee (p)	Ankle (p)	<6 mo (p)	≥6 mo (p)
Step length SI	<0.001	<0.001	0.158	<0.001	<0.001	<0.001	<0.001
Stride length SI	<0.001	<0.001	0.856	<0.001	0.010	<0.001	<0.001
Step time SI	<0.001	0.017	0.266	<0.001	0.013	0.004	0.002
Stride time SI	<0.001	<0.001	0.886	<0.001	0.162	<0.001	0.004
SLS time SI	<0.001	<0.001	0.991	<0.001	<0.001	<0.001	<0.001
Swing time SI	<0.001	<0.001	0.111	<0.001	<0.001	<0.001	<0.001

Note. SI = symmetry index; SLS = single-limb support; mo = months. Non-normal distributions support non-parametric analyses throughout.

Affected vs. Unaffected Limb — Raw Parameter Comparison

Step length was the only parameter that differed significantly between limbs: the affected limb was significantly shorter than the unaffected limb (51.2 ± 10.0 cm vs. 52.8 ± 13.9 cm; W=735.5; p=0.028; r=0.24). No significant between-limb differences were observed for stride length (p=0.799), step time (p=0.484), stride time (p=0.808), SLS time (p=0.728), or swing time (p=0.272) (Table 4).

Table 4: Wilcoxon signed-rank test: affected vs. unaffected limb spatio-temporal parameters (n=65).

Parameter	Affected Mean (SD)	Unaffected Mean (SD)	W-statistic	p-value
Step length (cm)	51.2 (10.0)	52.8 (13.9)	735.5	0.028*
Stride length (cm)	96.5 (21.5)	96.5 (22.0)	1033.5	0.799
Step time (s)	0.6 (0.2)	0.6 (0.2)	588.5	0.484
Stride time (s)	2.8 (12.0)	1.3 (0.3)	741.0	0.808
SLS time (s)	1.1 (5.3)	0.5 (0.3)	626.0	0.728
Swing time (s)	0.4 (0.1)	0.4 (0.1)	524.0	0.272

*Note. * $p < 0.05$. SLS = single-limb support. Effect size step length: rank-biserial r = 0.24.*

Symmetry Index — Management Type

Step-length SI was significantly greater in the surgical group than the conservative group (16.0 ± 21.0% vs. 10.6 ± 21.0%; U=347; p=0.018; r=0.32), exceeding the 10% clinically meaningful threshold in both groups but substantially more so in the surgical group. No significant differences were found for other SI parameters (p ≥ 0.115) (Table 5).

Table 5: Mann-Whitney U test: symmetry indices by management type (conservative vs. surgical).

SI Parameter	Conservative Mean (SD) %	Surgical Mean (SD) %	U-statistic	p-value
Step length SI	10.6 (21.0)	16.0 (21.0)	347.0	0.018* (r=0.32)
Stride length SI	4.5 (4.1)	6.7 (7.6)	438.0	0.240
Step time SI	9.1 (10.1)	12.9 (10.3)	408.0	0.115
Stride time SI	16.3 (43.1)	5.9 (5.6)	559.0	0.688
SLS time SI	21.4 (38.4)	20.3 (24.9)	464.0	0.402
Swing time SI	13.0 (14.3)	18.9 (22.7)	487.5	0.597

*Note. * p < 0.05. SI = symmetry index; SLS = single-limb support. Holm-Bonferroni correction applied.*

Symmetry Index — Injury Site

No significant SI differences were detected across injury sites (all p ≥ 0.32; $\varepsilon^2 \leq 0.06$). Step-length SI values: hip 11.3 ± 9.5%; knee 12.8 ± 20.3%; ankle 15.1 ± 25.6% (H=0.721; p=0.697), indicating a generalised loading-avoidance pattern rather than site-specific adaptations (Table 6).

Table 6: Kruskal-Wallis test: symmetry indices across hip, knee, and ankle injury sites.

SI Parameter	Hip Mean (SD) %	Knee Mean (SD) %	Ankle Mean (SD) %	H-statistic	p-value
Step length SI	11.3 (9.5)	12.8 (20.3)	15.1 (25.6)	0.721	0.697
Stride length SI	4.9 (2.7)	5.8 (6.8)	4.9 (4.6)	0.143	0.931
Step time SI	10.9 (13.4)	10.8 (9.3)	11.6 (12.8)	0.125	0.939
Stride time SI	5.6 (5.1)	13.9 (37.1)	4.8 (3.9)	0.701	0.704
SLS time SI	9.0 (7.3)	22.4 (34.4)	19.7 (30.2)	1.181	0.554
Swing time SI	12.5 (16.6)	17.4 (19.4)	12.7 (19.1)	2.257	0.324

Note. No significant between-site differences. $\varepsilon^2 \leq 0.06$ (trivial effect sizes). SI = symmetry index; SLS = single-limb support. Hip n=4, knee n=45, ankle n=16.

Symmetry Index — Recovery Duration

Participants assessed within six months of rehabilitation showed significantly greater SLS-time SI than those assessed later (27.5 ± 39.7% vs. 13.2 ± 18.2%; U=675; p=0.048; r=0.28). Step-length SI remained above the 10% threshold in both groups and did not differ significantly (p=0.229), indicating persistent spatial propulsion asymmetry regardless of time since discharge (Table 7).

Table 7: Mann-Whitney U test: symmetry indices by recovery duration (<6 months vs. ≥6 months).

SI Parameter	<6 Months Mean (SD) %	≥6 Months Mean (SD) %	U-statistic	p-value
Step length SI	14.4 (20.5)	11.9 (21.8)	617.0	0.229
Stride length SI	5.3 (6.1)	5.8 (6.2)	474.0	0.506
Step time SI	11.5 (10.5)	10.4 (10.3)	566.0	0.592
Stride time SI	16.0 (41.9)	5.5 (4.5)	558.5	0.663
SLS time SI	27.5 (39.7)	13.2 (18.2)	675.0	0.048* (r=0.28)
Swing time SI	18.4 (21.5)	13.0 (15.5)	612.0	0.252

*Note. * p < 0.05. SI = symmetry index; SLS = single-limb support. <6 months n=35; ≥6 months n=30.*

DISCUSSION

This study makes three distinct contributions. First, it demonstrates that symmetry indices derived from a low-cost 2D video tool are sensitive to clinically meaningful subgroup differences — by management type and recovery duration — invisible to raw spatio-temporal comparisons alone. Second, it provides, to our knowledge, the first SI-based gait data from a mixed lower-extremity injury cohort at rehabilitation discharge in an Indian outpatient setting. Third, it establishes that a pragmatic >10% SI threshold is clinically informative across injury sites, suggesting that site-specific thresholds may not be necessary in routine practice.

Persistent step-length asymmetry after rehabilitation aligns with recent systematic reviews and meta-analyses reporting incomplete restoration of propulsion and loading symmetry 6-12 months after ACLR, even in patients meeting discharge criteria [7, 8]. Long et al. (2025) [10] confirmed reduced step length and prolonged double-support persisting after ankle fracture surgery, and similar long-term deviations have been documented after arthroplasty 11, 12]. The absence of significant temporal differences for most raw parameters suggests that rhythmic timing may normalize earlier than spatial components of gait, consistent with the hypothesis that central pattern generator-driven timing recovers more rapidly than peripheral neuromuscular deficits underpinning forward propulsion.

Greater step-length SI in surgically treated participants is consistent with reports of prolonged spatial deficits after reconstructive procedures [8]. Papaleontiou et al. (2024) [21] demonstrated that conservative management may better preserve mechanoreceptor function, potentially facilitating more rapid spatial recalibration — consistent with our finding of lower step-length SI in the conservative group. The absence of injury-site SI differences (ε^2 < 0.05 throughout) supports the existence of a generalized unilateral loading-avoidance strategy, simplifying clinical implementation of SI-based screening across hip, knee, and ankle injuries.

Recovery-duration analyses indicate SLS-time asymmetry is most pronounced in the early post-rehabilitation phase and partially resolves by ≥6 months, consistent with staged recovery models in which stability and weight-acceptance recover before propulsion and metabolic economy. Notably, step-length SI remained >10% in both recovery duration groups, identifying spatial propulsion asymmetry as the most persistent residual impairment [22].

Clinical Implications

These results caution against discharge decisions based solely on raw parameters or qualitative observation. We propose a simple two-step clinical decision rule: (1) measure step-length SI using Kinovea — if SI exceeds 10%, do not discharge regardless of clinical strength or range-of-motion targets; (2) in patients assessed within six months of discharge, additionally measure SLS-time SI — if this exceeds 10%, continue weight-acceptance and stability-focused gait training before discharge. This approach requires no specialised equipment, takes approximately 10 minutes in a standard outpatient corridor, and can be implemented immediately in any physiotherapy department.

Propulsion-focused training (fast-walking drills, resisted terminal stance, eccentric loading) should target elevated step-length SI, while stability training (single-leg stance, perturbation, graded loading) should address elevated SLS-time SI [18]. Surgically managed patients may warrant extended monitoring and longer intervention windows for spatial symmetry restoration.

Strengths and Limitations

Strengths include comprehensive assessment across multiple clinically relevant subgroups, use of validated low-cost instrumentation (Kinovea; ICC >0.95) directly replicable in routine practice, appropriate non-parametric statistics with effect-size reporting, and a mixed cohort reflecting real-world outpatient heterogeneity.

Limitations include single-center convenience sampling, self-selected walking speed — though this deliberately reflects ecological outpatient conditions and the parameters analyzed are primarily sagittal-plane measures for which 2D analysis is well-validated [19, 20] and reliance on sagittal-plane 2D analysis that cannot capture frontal- or transverse-plane compensations. The small hip subgroup (n=4) also limits site-specific conclusions.

CONCLUSION

To our knowledge, this is the first study to systematically compare raw spatiotemporal gait parameters with symmetry indices across a mixed cohort of conservatively and surgically managed lower-extremity injuries — encompassing hip, knee, and ankle sites — using a validated two-dimensional video-based workflow in a real-world Indian outpatient physiotherapy department. Step-length asymmetry is the predominant residual gait impairment after rehabilitation and is more sensitively detected by symmetry indices than by raw comparisons. Surgical management is associated with greater step-length asymmetry than conservative care, and SLS-time asymmetry is most pronounced early after rehabilitation, before partially resolving. These findings support routine use of symmetry indices with a pragmatic >10% threshold to refine discharge decisions, individualize rehabilitation, and better address ongoing compensatory gait patterns in outpatient physiotherapy settings.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI

Generative AI tools were not used in the collection, analysis, or interpretation of data. AI assistance was used solely for language editing and formatting of the manuscript text. The authors take full responsibility for the integrity and accuracy of the work.

Ethics Approval

Approved by the Institutional Ethics Committee, JSS Hospital

Approval Number: JSS/IEC/2022/090721

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Informed Consent: Written informed consent was obtained from all participants prior to participation.

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