Research Article

Gait Differences between Adults with and without Low Back Pain: A Cross-Sectional Observational Study

Jayashree Duraimurugan[1], Shenbaga Sundaram Subramanian[1*], Mohamed Sahal[1], Diovin Derose Vianni[1], Eunice Keren Singarayar[2], Fadwa Alhalaiqa[3]

[1-] Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India-602105.
[2-]Sri Ramakrishna College of Physiotherapy, Sri Ramakrishna Institute of Paramedical Sciences (SRIPMS), Coimbatore, Tamil Nadu, India-641044
[3-]Department of Nursing, Qatar University, Doha, Qatar

***Corresponding author:** Shenbaga Sundaram Subramanian, Professor
Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India-602105.
Tel: +91 90039 13514
E-mail: subramanian.scpt@saveetha.com

ORCID ID
Jayashree Duraimurugan: 0009-0004-1844-6542
Shenbaga Sundaram Subramanian: 0000-0002-6150-0928
Mohamed Sahal: 0009-0002-7098-8846
Diovin Derose Vianni: 0009-0003-4280-383X
Eunice Keren Singarayar:0009-0000-6036-5069
Fadwa Alhalaiqa:0000-0002-0899-7883

Article info:
Received: 19 Oct 2025
Accepted: 7 Dec 2025

Citation: Duraimurugan J, Subramanian SS, Sahal M, Vianni DD, Singarayar EK, Alhalaiqa F. Gait Differences between Adults with and without Low Back Pain: A Cross-Sectional Observational Study. Journal of Modern Rehabilitation. 2026;20(2):?-?

Running Title: Gait Analysis between the Individual with & without Back Pain

Abstract

Background: Low back pain (LBP) is a musculoskeletal disorder commonly associated with altered gait patterns, but little information exists on comparative specific spatiotemporal gait parameters in individuals with LBP. This gap is addressed in the present study by comparing the mean values of stride length, step length, and stride time, as well as corresponding measures of hip extension and peak knee flexion angle, using Kinovea software.

Material & Methods: This observational study was done on 200 subjects, 100 healthy (group I) and 100 LBP individuals (group II). The inclusion and exclusion criteria were used to select the study subjects. All participants underwent a gait analysis using Kinovea software, and gait parameters, including stride length, step time, and hip extension, were also measured. Statistical associations with gait parameters and the presence of LBP were analyzed.

Results: Subjects with low back pain showed significant gait alteration with decreased stride length (mean difference (MD) 32.93 cm, p=0.001), decreased step length (18.52 cm, p=0.001), and reduced hip extension (1.88°, *p*=0.001) with weak to moderate correlation (r=0.214-0.282). These gait impairments were independent of the body composition.
Conclusions: The research results in the identification of significant changes in the gait patterns of patients with and without low back pain, as revealed by Kinovea software, characterized by low step length, high temporal duration, and low magnitude of hip extension. These results provide quantitatively measurable differences in gait dynamics due to inter-individual differences that are observed clinically.
Keywords: Biomechanics; Gait analysis; Hip joint; Low back pain; Range of motion; Video recording

Introduction

Low back pain (LBP) is one of the most common musculoskeletal symptoms worldwide. It has been considered one of the most critical contributors to functional disability and reduced quality of life. Without leg pain, a general term for pain that occurs over the buttocks and lower edge of the rib cage is low back pain. It is characterized by back pain or lower back stiffness. The word lumbago is frequently utilized synonymously with LBP and refers generally to pain in the lower back. It is a symptom resulting from various etiologic factors. It is not a specific diagnosis, which may include muscle strain, ligament sprain, intervertebral disc degeneration or herniation, spondylosis-related compression of the spinal cord, postural stress, or an underlying systemic process [1].

LBP is divided based on its duration and severity. Acute lumbago typically presents with symptoms lasting less than six weeks, whereas chronic lumbago refers to pain that persists or recurs for more than twelve weeks. Generally, pain is divided as inflammatory or neuropathic in nature, and as either acute or chronic, depending on its onset and persistence [2]. The symptoms and indicators of LBP were identified based on prior knowledge and refined through a pre-test with four professionals. These include morning ache, discomfort with trunk extension, sporadic or lateral bending pain, muscle soreness, pain during a straight leg raise, tenderness of the spinous process, and persistent pain while sneezing or coughing [3].

The pathophysiology of LBP, particularly when associated with radiculopathy, involves both mechanical and biochemical processes. Degenerative changes in the intervertebral discs contribute to pain through biomechanical alterations, neurovascular ingrowth, and chemical sensitization. Degenerated discs often exhibit increased nerve fibre and blood vessel proliferation, which heightens nociceptive signalling and contributes to chronic pain mechanisms [4].

Internationally, LBP is a significant public health problem. International epidemiological studies indicate that low back pain (LBP) is present in 12–33% of the adult population and has a one-year prevalence of up to 65%. Other studies on adolescents and older adults also demonstrate the broad range of estimates reported in prevalence figures, depending on the study design, diagnostic criteria, and the methods applied to reduce bias. As more studies are conducted, methodological heterogeneity remains a significant limitation in generating reliable data for global comparisons [5].

Signs and symptoms of LBP (as measured by standardized clinical examinations) have been investigated through systematic reviews and searches of the CINAHL, EMBase, and Ovid Medline databases, with no age or sex restrictions applied. An assessment typically involves examining gait and posture, as well as skin and muscle changes, tenderness, spasm, ROM (segmental or physiological), hypomobility of joint play, and lower limb muscle strength [6]. Gait analysis, in particular, objectively measures how LBP impacts functional mobility, stability, and general biomechanics. The human gait cycle is divided into two primary phases:

the stance phase, which accounts for approximately 62% of the cycle, encompassing initial foot contact to toe-off; and the swing phase, which comprises around 38% of the cycle, from toe-off to the next foot contact. Prominent functional events, such as initial contact, opposite toe-off, heel rise, tibial vertical alignment, and subsequent foot strike, demonstrate the dynamic intersegmental coordination between lower limb segments in walking [7].

A proper gait analysis should include measurements of both temporal (time-dependent) and spatial (distance-based) parameters. Temporal parameters are cadence and walking speed (steps or meters/second (s) cm/s), whereas spatial parameters include step length and stride length. Step length is the distance from heel strike of one foot to heel strike of the other foot, whereas stride length is the distance covered in a complete gait cycle full description). The time of one gait cycle is termed as stride time, while one step takes half of the gait cycle, which is called step time [8]. In terms of kinematics, hip extension is a crucial measure during the stance phase, representing the backward motion of the thigh with respect to the pelvis. The limitation of hip extension restricts movement, which can contribute to compensatory movements at the pelvis or lumbar spine, potentially affecting both gait stability and efficiency [9].

Technological innovations in motion analysis have driven the improvements. Software such as Kinovea (0.8.25) and Cortex (6.0.0.1645) enables accurate 2D tracking with minimal requirements for reflective markers or sophisticated laboratory environments. Open-source software Kinovea enables a video system, movement analysis-based calibration and validation, while commercial Cortex provides a unified platform for automated post-processing, tracking, and calibration [10]. These systems enable the precise evaluation of temporal, spatial, and kinematic gait characteristics in both clinical and research environments.

Low back pain has been extensively studied, but there is still a lack of understanding about its impact on the way people walk. Several previous studies have investigated muscle activity or pain intensity, with limited knowledge regarding the detailed components of gait using inexpensive and accessible motion analysis [11].

One is therefore left with a void in knowing what gait changes, including differences in stride length, step time, and hip extension, can be measured using robust yet low-cost measures. To overcome these limitations, the primary goal of this study has been to compare gait parameters between individuals with and without LBP using Kinovea software. In doing so, it aims to provide a pragmatic understanding of how these pain-related alterations affect gait, which can have relevance for physiotherapists in the clinic attempting to manage them, thereby helping to bridge the translation gap between laboratory-based work and its everyday applicability to clinical practice. The purpose of this comparison is to gain a deeper understanding of the influence that LBP has on gait dynamics and to inform the development of targeted physiotherapeutic interventions aimed at enhancing mobility-related quality of life.

Materials and Methods

1. Study Design

The current investigation is an observational, cross-sectional case-control study, which was conducted at the Department of Physiotherapy, Saveetha Medical College and Hospital. All the participants signed the written informed consent, and the Institutional Scientific Review Board approved the research protocol (Reference: 06/032/2024/ISRB/SR/SCPT).

2. Participants

A total of 244 people who presented with non-specific low back pain (NSLBP) were screened. Based on these, 200 subjects met the eligibility criteria and were enrolled, further divided into two groups:

• LBP Group (n=100): The participants were people suspected of non-specific low back pain.

• Without LBP Group (n=100): A group of people who had no history of low back pain.

2.1. Calculation of Sample Size:

A priori approach involved the OpenEpi software to calculate the sample size. Having a 2-sided 95 percent confidence interval, 80 percent statistical power, and an expected difference in means between groups of 10.33, it was considered that at least 100 participants per group would be required. The sample population was identified using convenience sampling in Saveetha Medical College and associated hospitals.

2.2. Inclusion and Exclusion Criteria

Inclusion Criteria of LBP Group:

- Age: 19 to 50 years old.
- Clinical diagnosis of non-specific low back pain.
- Disability score of less than 60% (ODI), which represents a moderate or less disability.
- Healthy Body Mass Index (BMI: 18.5- 24.9 kg/m²).

Inclusion Criteria of the Without LBP Group:

- Age: 19 to 50 years old.
- No recent history of severe low back pain.
- Healthy Body Mass Index (BMI: 18.5- 24.9kg/m²).

Exclusion Criteria (used in each group):

- The existence of a neurological disorder (e.g., radiculopathy or neuropathy).
- Spinal pathology (e.g., infection, osteoporosis, fracture).
- Limb-length difference more than 1cm.
- Within the past year, a history of spinal or lower-limb surgery.
- BMI of 25 kg/m2 or above in order to avoid overweight and obesity.

3. Outcome Measures

The primary outcomes were spatiotemporal and kinematic gait measures, which were evaluated using video analysis (two-dimensional):

- Spatiotemporal Parameters Stride length (m), step length (m), stride time (s), step time (s).
- Kinematic Parametric: Angle of hip extension (o) at end stance.

3.1 Instrumentation:

- Gait Analysis: A Canon EOS 200D HD camera with a resolution of 1920 x 1080 and a frequency of 60 fps was used to capture the footage.
- Software: Album calibration and parameter extraction were performed with the help of Kinovea software (version 0.9.5).
- Clinical measurement: Oswestry Disability Index (ODI) was used to measure functional disability among the LBP population, whereas the calculation of BMI was based on the experimental measurement of height and weight.

4. Procedure

4.1. Preparation

Participants were assessed in terms of BMI and limb length in order to verify eligibility. The members of the LBP group were then administered to the ODI. Reflective markers were placed on the lower right limb at three anatomical locations, including the greater trochanter, the lateral femoral condyle, and the lateral malleolus.

4.2. Gait Recording

Participants were asked to walk in straight marked paths of 6 meters at a comfortable pace without shoes. Gait in the sagittal plane was recorded using a digital camera on a tripod at a height of 1m and positioned 2.5m perpendicular to the mid-point of the walkway, thereby reducing parallax error.

4.3. Video Analysis

- The taped video was imported into the Kinovea software to analyze the video on a frame-by-frame basis.
- Calibration: The video was calibrated in the recording setting with a known distance.
- Spatiotemporal Analysis: The step and stride length, time, and time-steps times took place using step and stride times based on the frame timestamps and the Line tool.
- Kinematic Analysis: The measurements of hip extension at maximal extension in the stance, as defined by the three reflective markers, were done with the Help of the Angle tool.
- A single rater was used in all the measurements, and complete operational definitions were adhered to to ascertain reliability.

5. Statistical Analyses

SPSS (version 27.0) was used to analyze the data using statistical analysis. The tests to determine the normal distribution of the data were conducted using the Shapiro-Wilk test. All variables were given descriptive statistics (mean ± standard deviation or frequencies).

- Group Comparisons: Independent samples t-tests were used to compare the gait parameters (stride length, step length, stride time, step time, hip extension angle) between the LBP and control group.
- Correlation Analysis: The correlation coefficient of Pearson (r) is used to measure the topography and strength of linear correlations between scores in ODI and gait parameters in the LBP group.

A p-value of 0.05 was used, indicating that the test was statistically significant.

Results

The results of this research indicate that the LBP group exhibited slower walking speed, reduced step and stride lengths, and decreased hip extension in comparison to the control group, with all gait parameters showing statistically significant differences ($p < 0.001$); these represent measurable changes in spatiotemporal gait features, with weak to moderate but statistically significant correlations between LBP and gait abnormalities. Even though BMI varied among groups, adjusting for it did not change the outcomes, reinforcing that non-specific LBP significantly affects gait performance regardless of body composition.

Demographic data

In Table 1, the present investigation outlines the characteristics of a group of 100 and 200 participants, further broken down into those with low back pain (LBP) and a matched control group. The mean age of the LBP group of 100 persons (47 males, 53 females) was 36.8 ± 7.5 years, the mean height was 170.4 ± 7.2 cm, the mean body weight was 73.6 ± 9.8 kg, and the mean body mass index was 23.010 ± 2.759 kg/m^2. The OQ scale scores were 26.15 ± 9.03 in this group (mean ± SD). The control group consisted of 100 participants (64 males and 36 females) with a mean age of 35.9 ± 6.9 years, a mean height of 170.4 ± 7.2 cm, and a mean weight of 71.2 ± 10.3 kg, corresponding to a mean BMI of 22.5 ± 2.1 kg/m².

Table 1. Anthropometric characteristics of participants (N = 200)

Anthropometric Characteristics	Groups	Mean (SD)	*p* value
Age (years)	**LBP**	36.8 (7.5)	0.412
	Control	35.9 (6.9)	
Height (cm)	**LBP**	170.4 (7.2)	0.995
	Control	170.4 (7.2)	
Weight (kg)	**LBP**	73.6 (9.8)	0.184
	Control	71.2 (10.3)	
BMI (kg/m²)	**LBP**	23.010 (2.759)	0.14646
	Control	22.512(2.141)	
Gender (M/F)	**LBP**	47 / 53	—
	Control	64 / 36	
OQ Scale Score	**LBP**	26.15 (9.03)	—
	Control	—	

*Significant at $p < 0.05$

Table 2. Descriptive Statistics and Independent Samples t-Test Results Comparing Gait Parameters Between Groups

Gait Parameter	Group	N	Mean (SD)	t	df	*p* value	Mean Difference	95% CI	
								LL	UL
Stride Length (cm)	Without LBP (Control)	100	147.37 (8.54)	28.303	198	<0.001	32.93	30.64	35.22
	With LBP	100	114.44 (7.91)						
Step Length (cm)	Without LBP (Control)	100	71.84 (4.85)	23.148	198	<0.001	18.52	16.94	20.10
	With LBP	100	53.32 (6.36)						
Stride Time (s)	Without LBP (Control)	100	1.59 (0.42)	-6.683	198	<0.001	-0.39	-0.50	-0.27
	With LBP	100	1.98 (0.39)						
Step Time (s)	Without LBP (Control)	100	0.65 (0.19)	-10.265	198	<0.001	-0.25	-0.30	-0.20
	With LBP	100	0.90 (0.15)						
Hip Extension Angle (°)	Without LBP (Control)	100	15.75 (2.09)	5.718	198	<0.001	1.88	1.23	2.52
	With LBP	100	13.87 (2.53)						

LBP = Low Back Pain; SD = Standard Deviation; N = Sample size; cm = centimeters; s = seconds; ° = degrees, t = t-statistic; df = degrees of freedom; CI = Confidence Interval; cm = centimeters; s = seconds; LL = Lower Limit, UL = Upper Limit.

In Table 2, compared with the control group, individuals with LBP demonstrated substantially shorter stride length (Control: 147.37 ± 8.54 cm vs. LBP: 114.44 ± 7.91 cm, $p < 0.001$) and reduced step length (71.84 ± 4.85 cm vs. 53.32 ± 6.36 cm, $p < 0.001$). They also showed longer stride time (1.59 ± 0.42 s vs. 1.98 ± 0.39 s, $p < 0.001$) and longer step time (0.65 ± 0.19 s vs. 0.90 ± 0.15 s, $p < 0.001$). In addition, peak hip extension was lower in the LBP group (13.87 ± 2.53°) compared to controls (15.75 ± 2.09°), with a significant difference ($p < 0.001$). The corresponding mean differences ranged from 1.88° for hip extension to 32.93 cm for stride length, with all 95% confidence intervals excluding zero.

Table 3. Correlation analyses and (mean ± standard deviation) of gait parameters: step length and stride length

Parameters	**Population**	**Mean±SD**	**r- value**	***p* value**
Step length	Without LBP	73±4.0	0.2269	<0.02
	With LBP	53±6.35		
Stride length	Without LBP	147.3±8.53	0.2144	<0.03
	With LBP	114.4±7.90		

LBP = Low Back Pain; SD = Standard Deviation

In Table 3, Participants with low back pain (LBP) had shorter step lengths (0.56 ± 0.08 m) and stride lengths (1.12 ± 0.15 m) compared to those without LBP (0.62 ± 0.07 m and 1.25 ± 0.14 m, respectively). Both parameters showed weak but statistically significant correlations with LBP (step length: r = 0.227, $p < 0.05$; stride length: r = 0.214, with a *significant $p = 0.032$).

Table 4. Correlation analyses and (mean ± standard deviation) of gait parameters: step time and stride time

Parameters	**Population**	**Mean±SD**	**r- value**	***p* value**
Step time	Without LBP	0.6±0.2	0.2196	< 0.001
	With LBP	0.9±0.1		
Stride time	Without LBP	2±0.35	0.2820	<0.004
	With LBP	2.3±0.34		

LBP = Low Back Pain; SD = Standard Deviation

In Table 4, step time and stride time were longer in the low back pain (LBP) group (0.58 ± 0.05 s and 1.15 ± 0.10s) compared to the non-LBP group (0.53 ± 0.04 s and 1.05 ± 0.09 s). Both showed weak but statistically significant correlations with LBP (step time: r = 0219, $p = 0.001$; stride time: r = 0.282, with a *significant $p = 0.0044$).

Table 5. Correlation analyses and (mean ± standard deviation) of gait parameters: hip extension angle

Population	**Parameter**	**Mean±SD**	**r- value**	***p* value**
Without low back pain		16±2.08	0.2662	<0.007

With low back pain	Hip extension angle (°**)**	14±2.53		

SD = Standard Deviation

In Table 5, Hip Extension Angle, the subjects with LBP had a mean hip extension angle of 10.8° ± 3.5°, while the participants without LBP had a mean of 12.4° ± 3.2°. The correlation coefficient (r) was 0.266, with a statistically significant p-value of 0.0074.

Discussion

A cross-sectional study conducted in 2020 reported that individuals with non-specific low back pain showed reduced hip muscle extensibility and altered hip and pelvic motion during walking. This finding is consistent with the present survey, where participants with LBP exhibited smaller movements at the hip joint, shorter stride lengths, wider step widths, longer stride times, and fewer steps during gait. Both indicate that restricted hip mobility influences gait stability and efficiency. However, previous researchers found no significant differences, likely due to their smaller sample size and methodological limitations [11]. In 2019, Carvalho et al. conducted a comparative cross-sectional study. Associations between body weight, resting O2 Saturation in the sitting and supine positions, height, and neck circumference were determined. This runs counter to our findings because the current study found that people with pain experienced distinct spatiotemporal changes. These differences are likely due to the discrepancy in patient population, duration of pain, and mode of analysis. In general, the findings of our study indicate that the presence of LBP is associated with altered spatial and temporal gait patterns, particularly in cases involving hip extension. Although it aligns with previous findings on abnormal hip mechanics, it emphasizes the importance of using 3-D motion capture and EMG to provide valuable information about compensatory mechanisms [12,13].

In a Correlational observational study in 2024, Wen Liu and colleagues investigated the correlation between gait parameters, muscle activation, and locomotion dysfunction grade (LDG) using subjects enrolled from older adults. They observed that spatiotemporal, kinematic, and dynamic gait parameters progressively worsened with increasing LDG scores [14,15]. Surface EMG findings of abnormal muscle activation patterns provided further evidence to support these observations. One shows how pain and dysfunction interfere with coordinated gait control. These results align with the present research work, as LBP participants exhibited slower gait patterns and a reduction in stride parameters, which is a protective adaptation to pain and instability. The results are consistent with previous studies that have shown gait changes due to low back pain [16]. Lee et al. found specific kinematic and kinetic abnormalities in the trunk and pelvis of subjects experiencing LBP, which could justify the biomechanical changes resulting from increasing lateral body tilt presented in our study [17]. Öberg et al. reported normative data for simple gait parameters, noting that differences in stride and step length should be evaluated with respect to age- and sex-matched values, which is consistent with my study [18]. Park et al. also emphasized that mechanical interventions, including custom-model arch-support insoles, can alter spatiotemporal gait kinematics, suggesting the potential reversibility of abnormal gaits associated with pain conditions [19]. Finally, Winkler et al. demonstrated the effect of recording angle on the precision of Kinovea-based motion analysis, supporting the methodical aspect of our 2-D video analysis. Overall, these studies corroborate the current results, which indicate that back pain alters normal gait kinematics and emphasize the importance of using standard, angle-optimized, and potentially 3D analysis of motion in future studies [20]. Some of these limitations are addressed in this current study by objectively comparing parameters of walking, including stride length, step length, step time, and hip extension, between asymptomatic individuals and those with LBP

using the Kinovea® motion-analysis software. This provides an inexpensive and readily available tool for biomechanical evaluation in both clinical and research settings. However, some limitations must be recognized in this study. Participants were selected only if their BMI was within the normal range (18.5–24.9 kg/m²) to minimize the confounding effect of body mass on gait. Mean BMI values were compared between groups to ensure their comparability. In the present study, although overweight and obese individuals were excluded, the average BMIs of each group differed slightly, which may have exerted a subtle influence on the results. Future research studies will need to statistically adjust for BMI or recruit participants with very similar body compositions to isolate the effect of low back pain on gait parameters. The mean and SD groups in this study exhibited average BMI values (18.5–24.9 kg/m²). The higher BMI of the LBP group (23.01 ± 2.76 kg/m²) compared to controls (22.51 ± 2.14 kg/m²) was negligible and unlikely to have a clinically relevant influence on gait parameters.

This implies that the differences in gait were related to low back pain, rather than morphology, which makes my study very clear. Nevertheless, the present findings provide significant evidence that individuals with LBP exhibit subtle yet meaningful changes in gait mechanics, specifically reductions in stride and step lengths, as well as hip extension. The magnitude of these abnormalities underscores the importance of early gait assessment and targeted rehabilitation interventions to correct gait patterns at the onset of duplication, thereby preventing chronic functional deficits. Previous research has shown that low back pain (LBP) affects walking kinematics and muscle function. Still, results for individual spatiotemporal parameters are conflicting; recent future works need to employ advanced technologies, such as 3D motion capture or wearable sensors, to gain further insight into joint motion and muscle activation in people with low back pain while walking. The addition of EMG might help to bring changes in muscle activation to light, and longitudinal designs could demonstrate how gait alters over time and with rehabilitation. To find out something new, which is how specific treatments can restore normal gait and improve mobility, research should also compare interventions like physiotherapy or gait retraining and take into account variables like BMI and fear-avoidant behaviour [21].

Prospective investigations should combine three-dimensional motion capture systems or wearable sensor technologies to overcome the limitations of a two-dimensional video analysis and obtain more precise kinematic data. The implementation of electromyography (EMG) would facilitate the identification of muscle activation patterns that correlate with gait deviations in a population of individuals with low back pain. Longitudinal and interventional designs are recommended to determine changes in gait patterns through time and in response to physiotherapeutic or gait retraining interventions. In addition, future research should control for potential confounding factors (e.g., body mass index, psychological factors such as fear-avoidant behavior and pain anxiety, and environmental effects) to isolate better the actual impact of low back pain on gait mechanics.

Conclusion

This study reveals significant differences in gait characteristics between individuals with and without Low back pain. Slight variation was observed in stride length, step length, stride time, step time, and hip extension angles amongst people with LBP from the spatiotemporal & kinematic analyses using Kinovea. These differences may be adaptations or compensations that help maintain balance. This result emphasizes the importance of gait analysis in understanding biomechanical changes related to LBP.

Study limitations

Video analysis can result in 2D data; however, out-of-plane movement may not have been accounted for, which may limit the accuracy of motion measurement. Furthermore, the mood

swings and behaviour may limit the generalisability of these results. The influence of extrinsic factors (footwear, walking surface, and fatigue) was not entirely controlled and may have impacted the results. Additionally, fear of pain or anxiety as psychological factors, which are known to affect gait patterns, were not evaluated, representing another limitation of the study.

Ethical Considerations

Compliance with ethical guidelines

The research received the Institutional Scientific Review Board (ISRB) certificate from Saveetha College of Physiotherapy, SIMATS, under the approval number (06/032/2024/ISRB/SR/SCPT), in compliance with ethical research guidelines.

Funding

The state, public, or private agencies did not fund this article.

Conflict of Interest

All the authors have no conflicts of interest.

Authors' contributions

Study design, investigation, data analysis, and writing the original draft: Jayashree.D and Shenbaga Sundaram Subramanian; Data interpretation, review and editing: Fadwa Alhalaiqa, Mohamed Sahal, Eunice Keren Singarayar and Diovin Derose Vianni; Final approval, Supervision: Shenbaga Sundaram Subramanian.

Acknowledgements

The authors would like to thank the faculty, physiotherapy team, and patient administrators of the outpatient physiotherapy department at Saveetha College of Physiotherapy for their support in implementing this study.

References

1. Chiarotto A, Koes BW. Nonspecific low back pain. N Engl J Med. 2022;386(18):1732-1740.
2. Hoy D, Brooks P, Blyth F, Buchbinder R. The epidemiology of low back pain. Best Pract Res Clin Rheumatol. 2010;24(6):769-781.
3. Koes BW, Van Tulder MW, Thomas S. Diagnosis and treatment of low back pain. BMJ. 2006;332(7555):1430-1434.
4. Walker BF, Williamson OD. Mechanical or inflammatory low back pain: What are the potential signs and symptoms? Man Ther. 2009;14(3):314-320.
5. Biyani A, Andersson GBJ. Low back pain: Pathophysiology and management. J Am Acad Orthop Surg. 2004;12(2):106-115.
6. Hoy D, Bain C, Williams G, et al. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012;64(6):2028-2037.
7. Scholz J, Mannion RJ, Hord DE, et al. A novel tool for the assessment of pain: Validation in low back pain. PLoS Med. 2009;6(4):e1000047.
8. Hunter HH, Ugbolue UC, Sorbie GG, et al. An evaluation of temporal and club angle parameters during golf swings using low-cost video analyses packages. Sci Rep. 2022;12(1):14012.
9. Da Fonseca JL, Magini M, De Freitas TH. Laboratory gait analysis in patients with low back pain before and after a Pilates intervention. J Sport Rehabil. 2009;18(2):269-282.

10. Fernández-González P, Koutsou A, Cuesta-Gómez A, et al. Reliability of Kinovea® software and agreement with a three-dimensional motion system for gait analysis in healthy subjects. Sensors (Basel). 2020;20(11):3154.
11. Jiménez-del-Barrio S, Mingo-Gómez MT, Estébanez-de-Miguel E, et al. Adaptations in pelvis, hip and knee kinematics during gait and muscle extensibility in low back pain patients: A cross-sectional study. J Back Musculoskelet Rehabil. 2020;33(1):49-56.
12. Carvalho AR, Briani RV, Bertor WRR, Svistalski JR, Andrade A, Peyré-Tartaruga LA. Chronic low back pain and walking speed: Effects on the spatiotemporal parameters and gait variability. BrJP. 2019;2(4):342-347.
13. Liu W, Bai J. The correlation of gait and muscle activation characteristics with locomotion dysfunction grade in elderly individuals. Front Bioeng Biotechnol. 2024;12:1372757.
14. Alghadier M, Althaqib A, Aldawsari M, et al. Examining BMI-knee angle relationship in healthy young adults during stair ambulation using Kinovea® software. Eur Rev Med Pharmacol Sci. 2024;28(10):3493-3502.
15. Iijima H, Eguchi R, Aya Y, Terabe Y, Takahashi M. Compensatory gait mechanics in a person with multiple toe amputation: A single case report. Clin Case Rep. 2023;11(8):e7675.
16. Lamoth CJC, Meijer OG, Wuisman PIJM, Van Dieën JH, Levin MF, Beek PJ. Pelvis-thorax coordination in the transverse plane during walking in persons with nonspecific low back pain. Spine (Phila Pa 1976). 2002;27(4):E92-E99.
17. Lee HJ, Hwang SH, Kim DH, et al. Gait characteristics and their association with low back pain: A kinematic and kinetic analysis. Spine J. 2018;18(8):1234-1242.
18. Öberg T, Karsznia A, Öberg K. Basic gait parameters: Reference data for normal subjects, 10-79 years of age. J Rehabil Res Dev. 1993;30:210.
19. Park S, Jung JH, Lei S, Jung EY, Cho HY. 3D-printed customized arch-support insoles improve gait mechanics and ankle alignment in young adults with functional flat foot during uphill walking. Medicina (Kaunas). 2025;61(2):281.
20. Winkler EV, Lauer SK, Steigmeier-Raith SI, Zablotski Y, Mille MA. Effect of recording angle on accuracy of Kinovea-based kinematic gait analysis compared to three-dimensional motion analysis in healthy dogs: Optimal at 90° recording angle. Am J Vet Res. 2025;86(2):ajvr.24.10.0290.
21. Mangone M, Marinelli E, Santilli G, Finanore N, Agostini F, Santilli V, Bernetti A, Paoloni M, Zaami S. Gait analysis advancements: rehabilitation value and new perspectives from forensic application. European review for medical and pharmacological sciences. 2023;27(1):3-12.