

ORIGINAL ARTICLE

Walking through Low Back Pain: A Comprehensive Review of Gait Research.

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Abstract

Background: Low back pain (LBP) is one of the most prevalent musculoskeletal conditions and a leading cause of disability worldwide, often associated with altered walking patterns that impair functional mobility. Despite widespread use of gait analysis in LBP research, the literature remains heterogeneous, making dominant research domains and trends difficult to identify. **Objective:** To map the research landscape on gait in individuals with LBP using bibliometric analysis, and to narratively synthesise the key research domains, commonly reported gait variables and measurement approaches, and emerging trends over time. **Methods:** A bibliometric analysis with narrative synthesis was conducted. The literature search was performed in the Web of Science Core Collection on 22 December 2025 Using a title-field search strategy. The search was restricted to English-language original and review articles examining gait, walking, ambulation, or mobility in individuals with LBP. Publication trend analysis and bibliometric keyword co-occurrence analysis using VOSviewer were performed to examine research output, thematic structures, and emerging trends. Findings from the bibliometric map were then narratively synthesised with reference to key primary studies to contextualise the identified domains. **Results:** Gait-related research in LBP has increased substantially, particularly after 2010. Keyword co-occurrence analysis identified three main thematic clusters: (1) biomechanics, motor control, and gait variability; (2) clinical assessment, rehabilitation, and functional outcomes; and (3) population characteristics, risk factors, and performance. Across these domains, individuals with LBP demonstrate altered trunk and lower-limb coordination, neuromuscular control, spatiotemporal parameters, and movement variability. Advances in measurement technologies, including three-dimensional motion capture and wearable sensors, have expanded gait assessment approaches. **Conclusion:** Gait research in LBP has evolved into a multidimensional field integrating biomechanical, clinical, and population-level perspectives. However, methodological heterogeneity and a lack of consensus on outcome selection limit comparability across studies. Domain-informed and condition-specific gait assessment frameworks are needed to improve methodological consistency and support clinical translation.

Keywords: *Bibliometric analysis, biomechanics, gait, low back pain, motor control, rehabilitation, wearable sensors.*



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Introduction

Low back pain (LBP) is one of the most prevalent musculoskeletal conditions worldwide and a leading cause of disability and reduced quality of life [1,2]. Walking is a fundamental activity of daily living that is frequently affected in individuals with LBP, often resulting in altered gait patterns and reduced functional mobility. Understanding gait-related alterations in this population is therefore essential for effective clinical assessment, rehabilitation planning, and evaluation of functional outcomes.

Over the past decades, gait research in LBP has expanded considerably, encompassing a wide range of movement domains, outcome variables, and measurement approaches. Broadly, this literature has examined trunk and lower-limb movements, inter-segmental coordination, gait kinematics and kinetics, spatiotemporal parameters, and gait variability. Gait variability, which reflects stride-to-stride fluctuations in movement patterns or gait parameters, has gained increasing attention as an indicator of motor control adaptability and stability [3,4]. Within these domains, individuals with chronic non-specific LBP have consistently demonstrated altered movement strategies during walking. For example, reduced pelvic rotation accompanied by relatively preserved thorax motion has been reported during walking and running, alongside changes in knee joint angles and trunk inclination under different walking conditions, highlighting the complexity of gait adaptations associated with LBP [3,4].

Inter-segmental coordination represents another key focus of gait research in LBP and refers to the temporal relationship between movements of different body segments, such as the trunk, pelvis, and lower limbs, during walking. Individuals with persistent LBP have been reported to exhibit more in-phase coordination patterns and alterations in coordination variability between the trunk and pelvis compared with healthy controls. Altered trunk–pelvis movement patterns during gait further illustrate how LBP can influence the coordination and integration of body segments,

even during relatively simple locomotor tasks [5,6].

Gait kinematics and kinetics have also been extensively investigated in individuals with LBP. Gait kinematics describe the angular displacement and motion of body segments and joints during walking, whereas gait kinetics concern the forces and moments that generate and regulate movement, including ground reaction forces and joint moments. Commonly reported spatiotemporal parameters, such as stride length, cadence, and gait speed are often altered in people with LBP [6]. In addition, analyses of ground reaction forces and loading rates have revealed altered mechanical demands during walking, suggesting compensatory strategies that may be adopted in response to pain or impaired motor control [7,8].

Advances in measurement technology have further shaped gait research in LBP. Three-dimensional motion capture systems are widely used to quantify joint kinematics and inter-segmental coordination with high precision, while electromyography (EMG) provides insight into neuromuscular activation patterns, particularly of the trunk and lumbar musculature. More recently, inertial measurement units (IMUs) have enabled gait assessment in both laboratory and real-world settings, and force plates continue to play a central role in capturing kinetic variables such as ground reaction forces and moments [9,10].

Emerging research trends indicate a growing emphasis on gait stability, balance, and functional performance in individuals with LBP. Recent studies have also begun to explore the influence of cognitive and psychological factors—such as fear of movement and pain-related anxiety—on gait behaviour. The integration of advanced analytical techniques, including wearable technologies and artificial intelligence-based approaches, has further expanded the scope of movement assessment and rehabilitation research [11,12].

Contemporary gait research in LBP increasingly adopts a multidimensional approach, combining

biomechanical, kinematic, and psychophysical assessments to provide a more comprehensive understanding of walking impairments. This holistic perspective acknowledges the complex interaction between biomechanics, neuromuscular control, and psychological factors, offering deeper insights into movement behaviour and functional limitations associated with LBP [4,13].

Against this background, the objective of the present study is two-fold: first, to map the research landscape on gait in individuals with LBP using bibliometric analysis, and second, to narratively synthesise the predominant gait domains studied, the gait variables most commonly reported, and the measurement approaches employed. By consolidating evidence across biomechanical, neuromuscular, and functional perspectives, this review aims to clarify current research trends and gaps and to provide a structured foundation for the development of condition-specific gait assessment frameworks for individuals with low back pain.

Methods

Study design

This study employed a bibliometric analysis with narrative synthesis. The bibliometric component was used to map publication trends and thematic structures, while the narrative synthesis contextualised the identified domains with reference to key primary studies. This design was chosen because it allows a structured overview of a heterogeneous field while acknowledging that a full systematic review with meta-analysis was not feasible given the variability in gait outcomes and study designs.

Search strategy

The literature search was conducted in the Web of Science Core Collection on 22 December 2025. The search was performed in the title field to capture publications with a primary focus on gait and LBP. The gait-related terms were “Gait,”

“Walking,” “Ambulation,” and “Mobility,” while the LBP-related terms were “Low Back Pain,” “Mechanical Low Back Pain,” “Postural Low Back Pain,” “Posterior Compartment Low Back Pain,” “Low Backache,” “Lumbago,” and “Recurrent Low Back Pain.” The two sets of terms were combined using the Boolean operator AND, while terms within each set were combined using OR.

The complete Web of Science search string was: TI= ("Gait" OR "Walking" OR "Ambulation" OR "Mobility") AND TI= ("Low Back Pain" OR "Mechanical Low Back Pain" OR "Postural Low Back Pain" OR "Posterior Compartment Low Back Pain" OR "Low Backache" OR "Lumbago" OR "Recurrent Low Back Pain")

The search was restricted to English-language publications and document types classified as Article or Review Article.

Eligibility criteria and study selection

Studies were included if they: (1) were original research or review articles; (2) were published in English; (3) examined gait, walking, ambulation, or mobility in individuals with LBP; and (4) reported at least one gait-related outcome. Studies were excluded if they were conference abstracts, editorials, letters, or full texts unavailable.

The initial search retrieved 341 records. Application of the defined filters (English-language; Article or Review Article) excluded 54 records, leaving 287 records. A further nine records were excluded because they were available only as abstracts and did not represent full-text publications. Consequently, 278 publications were retained for the final analysis. A flow diagram summarising the identification, screening, and inclusion process is presented in Figure 1.

Data extraction

For each included publication, the following data were extracted: authors, year of publication, journal, country of author affiliation, document type, and author keywords. Data extraction was performed by one reviewer (NM) and verified by

a second reviewer (SAB). Disagreements were resolved through discussion.

Bibliometric analysis

The final Web of Science records were exported in plain-text format, including full records and cited references, and subsequently imported into VOSviewer (version 1.6.20) for bibliometric analysis. Co-occurrence analysis of author keywords was performed to identify the major thematic structures within gait-related LBP research. A minimum occurrence threshold of 10 was applied to identify frequently occurring keywords and ensure meaningful network connections. The number of keywords meeting this threshold, total link strength, and network metrics (modularity and silhouette) were recorded. A sensitivity analysis was conducted using a minimum occurrence threshold of 5 to assess the robustness of the cluster structure. VOSviewer was used to generate network visualization maps, in which nodes represent keywords, links indicate co-occurrence relationships between keywords, and link strength reflects the strength of their co-occurrence. Related keywords were automatically grouped into thematic clusters using the VOSviewer clustering algorithm. Cluster labels were assigned by two reviewers (NM and SAB) based on the dominant keywords within each cluster, and disagreements were resolved through discussion.

Narrative synthesis

Following the bibliometric analysis, a narrative synthesis was conducted to contextualise the identified clusters with reference to key primary studies. This synthesis focused on the gait domains, variables, and measurement tools represented within each cluster. Studies were selected for inclusion in the narrative synthesis if they were highly cited, methodologically robust, or representative of a specific gait domain. No formal quality appraisal was conducted, and the synthesis should therefore be interpreted as descriptive rather than definitive.

Results

Characteristics of included publications

A total of 278 publications were included in the final analysis, spanning the period from 1974 to 2025. Research output was highest in 2025 ($n = 28$), followed by 2021 ($n = 23$) and 2023 ($n = 21$). It should be noted that the 2025 figure represents a partial year, as the search was conducted in December 2025. Based on author-affiliation countries using full counting, the United States ($n = 72$) contributed the largest number of publications, followed by the Netherlands ($n = 23$) and Australia ($n = 20$). Full counting means that each author's country is counted, so a single publication with authors from multiple countries contributes to each country's count. The most frequently represented journals were *Spine* ($n = 18$), *Gait & Posture* ($n = 17$), and the *European Spine Journal* ($n = 13$).

Descriptive analysis of publication trends

Figure 2 presents the annual total publications (TP) and total citations (TC) related to gait research in LBP, revealing a clear evolution of scholarly interest over five decades. From 1974 through the early 1980s, research activity was minimal, with either no publication or only isolated studies each year and negligible citation impact. The first notable increase emerged in the mid-to-late 1980s and early 1990s, where modest but steady publication activity was accompanied by rising citation counts. This suggests that some foundational studies published during that period garnered attention despite the low annual output. Peaks in citation counts in the early 1990s (e.g., around 1991–1993) and in 1996 indicate that a few influential works from those years had a shaping effect on subsequent gait and LBP research.

A substantial growth phase began after 2000, marked by a steady rise in both the number of publications and the accumulation of citations. Notably, sharp increases in citation counts were observed in 2006 and 2010, which corresponded with years of moderate-to-high publication output.

This pattern suggests the dissemination of highly impactful studies around those times. From 2015 onwards, the field experienced a pronounced surge in publication volume, reaching a peak of 28 publications in 2025. In contrast, total citation counts showed a downtrend in the most recent years, likely reflecting the typical lag in citations for newly published work [14]. Overall, the data illustrates a shift from sporadic early research to a mature and rapidly expanding research field. The most recent years are characterised by high research productivity, although the citation impact of these new studies is still emerging.

Key research keywords of gait and low back pain

A co-occurrence analysis of author keywords was conducted using VOSviewer. The software employs a distance-based visualisation approach combined with a modularity-based clustering algorithm to group keywords according to their patterns of co-occurrence. In this analysis, link strength represents the frequency with which two keywords co-occur across the included publications, with stronger links indicating closer conceptual relationships. Clusters were generated automatically by VOSviewer on the basis of these link strengths, enabling the identification of dominant thematic structures within the gait-related LBP literature.

To enhance the robustness of the analysis, a minimum occurrence threshold of 10 was applied, ensuring that only frequently occurring and conceptually meaningful keywords were included in the network. A total of 42 keywords met this threshold and were included in the final network. The network had a total link strength of 1,247, modularity of 0.48, and silhouette score of 0.62, indicating a moderately well-structured cluster solution. A sensitivity analysis using a minimum occurrence threshold of 5 yielded a similar three-cluster structure, supporting the robustness of the findings. This approach reduced noise from infrequent or overly specific terms while preserving the core structure of the research field. The resulting keyword network provides an

overview of the principal research foci in gait-related LBP studies and illustrates how key concepts are interconnected. Figures 3 and 4 present the network visualization and the overlay visualization, respectively, highlighting the main thematic clusters and their temporal evolution. Table 1 summarises the key gait variables and measurement tools commonly reported across the included studies.

Cluster 1 (Red): Biomechanics, motor control and gait variability

The red cluster represents the core biomechanical and motor control domain of gait research in LBP. High-frequency keywords such as *gait*, *walking*, *coordination*, *kinematics*, *trunk*, *lumbar spine*, *variability*, *stability*, and *muscle activity* indicate a strong emphasis on how LBP influences movement control and inter-segmental coordination during walking. Strong co-occurrence links between terms like trunk–pelvis coordination, transverse plane motion, and gait variability suggest that this cluster captures foundational research examining altered motor strategies and reduced adaptability in individuals with LBP. These themes align with experimental and observational studies that have reported persistent changes in trunk and lower-limb coordination, as well as altered neuromuscular activation patterns, in individuals with LBP [5,9,15,16].

Cluster 2 (Green): clinical assessment, rehabilitation, and functional outcomes

The green cluster reflects a clinically oriented research theme focused on assessment, rehabilitation, and functional outcomes. Frequently co-occurring keywords in this cluster include *disability*, *exercise*, *exercise therapy*, *physiotherapy*, *management*, *questionnaire*, *reliability*, *validity*, and *physical activity*. This cluster highlights the translation of gait research into clinical practice, emphasising outcome measurement, intervention effectiveness, and functional improvement in individuals with LBP. The strong links observed between disability

measures and rehabilitation-related terms suggest that gait variables are commonly evaluated alongside patient-reported outcomes to guide treatment decisions and monitor recovery. This theme is well supported by intervention and validation studies that integrate gait assessment with therapeutic exercise and functional evaluation [17,18].

Cluster 3 (Blue): population characteristics, risk factors, and performance

The blue cluster encompasses a broader population-level and contextual perspective of gait research in LBP. Key terms in this cluster include *people, individuals, older adults, hip, performance, motion, prevalence, risk factors, and association*. These suggest studies examining how demographic factors, joint-specific contributions, and general performance characteristics relate to gait alterations. The presence of hip-related and performance-based keywords indicates a growing interest in proximal joint contributions and overall movement efficiency, particularly in ageing populations and specific subgroups of LBP sufferers. This cluster reflects epidemiological and observational research linking gait performance and movement characteristics with the risk, prevalence, and functional capacity in LBP populations [19,20].

Discussion

This bibliometric and narrative review interpreted research trends and thematic structures in gait-related studies of LBP by integrating findings from publication trends and keyword co-occurrence analyses. The observed growth in publication volume, especially after 2010, is consistent with a rising recognition of gait as a clinically meaningful indicator of functional impairment in LBP. This trend parallels a broader shift in musculoskeletal research toward focusing on functional and activity-based outcomes rather than pain intensity alone [2, 14]. Similar patterns of growth have been reported in other movement-related LBP research, indicating that gait is

increasingly seen as a window into persistent movement adaptations and the mechanisms of disability [15]. The lower density of citations for recent years is likely due to the latency of citations rather than a reduction in scientific value—a common phenomenon in fast-growing, interdisciplinary fields [21].

The prominence of the biomechanics and motor control cluster underscores the foundational role of movement science in explaining gait alterations associated with LBP. Numerous studies have shown that individuals with LBP exhibit altered trunk–pelvis coordination, reduced transverse-plane motion, and modified neuromuscular strategies during walking [5,16,17]. Collectively, these findings indicate that altered movement control is an important feature investigated within the LBP gait literature. However, the presence of such alterations should not be interpreted as evidence of long-term motor reorganization or as a direct consequence of LBP, particularly given the heterogeneity of study designs and populations represented. Rather, the findings suggest that gait-related motor control differences may coexist with LBP and warrant further longitudinal investigation to clarify their temporal relationship and clinical significance. Modelling and simulation studies have additionally reported differences in lumbar loading patterns and muscle activation strategies during gait in chronic LBP populations [4,18], further illustrating the range of biomechanical and neuromuscular characteristics investigated within this field.

The strong emphasis on gait variability and stability in the keyword analysis reflects an important conceptual evolution in the field. Early interpretations often framed reduced variability as a protective mechanism to limit spinal motion. However, contemporary research increasingly views variability as a marker of adaptability and motor flexibility [19]. Studies have reported altered gait variability and constrained coordination patterns in individuals with LBP, potentially reflecting reduced adaptability to changing task and environmental demands

[16,20]. However, these alterations are not necessarily uniform across individuals, tasks, or movement domains. Alsubaie et al. [20], in their systematic review of movement variability in people with chronic non-specific LBP, highlighted heterogeneity in the direction and magnitude of variability-related findings across the literature. This suggests that the prominence of variability within the present keyword analysis reflects increasing research attention to movement adaptability rather than evidence of a consistent pattern of increased or reduced variability in LBP. This shift toward non-linear analyses and variability-based metrics aligns gait research in LBP with modern motor control theory and may provide additional insight into movement characteristics that are not captured by conventional discrete gait measures. The present bibliometric analysis cannot resolve this heterogeneity, but it does highlight variability as an increasingly prominent research focus that warrants further methodological standardisation. These findings can be considered alongside the systematic review and meta-analysis by Smith et al. [6], which examined differences in walking between individuals with LBP and back-healthy controls. Their review identified differences across several gait characteristics while also highlighting substantial heterogeneity in the magnitude and consistency of findings across studies. The present review complements this evidence by showing that the gait-related LBP literature has expanded beyond conventional spatiotemporal outcomes to encompass inter-segmental coordination, neuromuscular control, movement variability, clinical assessment, and emerging measurement technologies. Thus, whereas Smith et al. focused on synthesising evidence of gait differences associated with LBP, the present analysis provides a broader mapping of the research landscape and identifies thematic clusters that may inform future research priorities. However, unlike Smith et al., the present review did not quantitatively synthesise effect sizes, and its findings should therefore be

interpreted as complementary rather than confirmatory.

The clinical assessment and rehabilitation cluster highlights the growing translational focus of gait research in LBP. Gait parameters are increasingly being evaluated alongside disability indices, physical activity measures, and treatment outcomes to inform rehabilitation strategies [21]. Intervention studies have shown that improvements in trunk control, balance, and movement confidence are often accompanied by measurable changes in gait speed, symmetry, and stability following exercise-based rehabilitation [21]. This integration suggests that gait assessment may complement patient-reported and clinical measures by providing an objective representation of walking performance. However, the heterogeneity of gait variables, assessment protocols, and intervention approaches across studies limits the extent to which specific gait measures can currently be recommended as standard indicators of rehabilitation response. Future research should therefore prioritise consensus on core gait outcome sets and standardised assessment protocols to facilitate comparison across intervention studies.

The third cluster, focusing on population characteristics and performance, highlights the importance of considering demographic and contextual factors in gait research. Studies examining lower-limb biomechanics have reported altered movement patterns at the hip and lower limb during walking in individuals with CLBP [15,17]. These findings highlight the importance of considering whole-body movement characteristics when interpreting gait in LBP, rather than assuming that observed gait differences originate specifically from the lumbar region.

Technological advancements have also shaped recent research trends, as reflected by the increasing prominence of wearable sensors, IMUs, and advanced analytical techniques. Wearable gait assessment has enabled capturing walking behaviour in real-world environments, revealing differences between laboratory gait and

daily-life gait patterns in individuals with musculoskeletal conditions [11, 22]. Nevertheless, differences in devices, sensor placement, gait protocols, and analytical approaches may limit direct comparison across studies. Therefore, technological advancement should be accompanied by greater methodological standardization to facilitate interpretation and clinical translation of gait-related findings.

From both research and clinical perspectives, the trends identified in this review highlight the need for a more structured and multidimensional approach to gait assessment in LBP. Rather than relying predominantly on spatiotemporal measures such as gait speed, cadence, and step length, assessment could incorporate complementary domains including trunk and lower-limb kinematics, inter-segmental coordination, gait variability and stability, and neuromuscular activity where clinically or experimentally relevant [19,20,22]. A condition-specific framework in this context refers to a structured approach in which the selection of gait outcomes is guided by the characteristics and functional presentation of individuals with LBP, while maintaining sufficient standardization in measurement and reporting to permit comparison across studies. Such an approach does not imply that every gait domain should be assessed in every individual; rather, it provides a common structure for selecting and reporting outcomes according to the research or clinical question. Future research should therefore prioritize harmonized reporting standards, longitudinal study designs, and subgroup-specific analyses to clarify the clinical relevance of different gait characteristics and to distinguish potentially adaptive from maladaptive movement strategies.

Beyond methodological considerations, the evolving research landscape also reflects increasing interest in interpreting gait within a broader biopsychosocial context. Gait characteristics in individuals with LBP may be considered alongside factors such as pain, disability, physical activity, fear-related responses, and movement behavior rather than

being interpreted solely as direct biomechanical consequences of pain [2, 20]. However, the available evidence does not establish whether observed gait alterations precede LBP, develop in response to symptoms, or persist as longer-term adaptations. This distinction is particularly important given the heterogeneity of LBP and the predominantly observational nature of much of the gait literature. Integrating biomechanical, behavioral, and psychosocial measures in future longitudinal research may therefore help clarify the relationships between gait characteristics, symptom status, and functional recovery.

Overall, the continued growth and diversification of gait research in LBP underline the importance of gait within multidisciplinary investigations of movement-related disability. However, the present analysis also reveals substantial variation in methodological approaches and outcome selection, which may limit comparability across studies and the translation of findings into clinical practice. Greater consistency in gait assessment protocols, outcome definitions, and reporting practices would facilitate comparison and synthesis across studies, while allowing researchers to select additional biomechanical, neuromuscular, or variability-based measures according to specific research questions. Future longitudinal and clinically oriented studies are needed to determine which gait characteristics are most relevant to functional status, treatment response, and recovery in individuals with LBP.

Strengths and limitations of the study

A key strength of this review is its combined bibliometric and narrative approach, which allowed for a structured interpretation of how research domains have evolved over time. The use of a sensitivity analysis to test the robustness of the cluster solution further strengthens the bibliometric component. By integrating biomechanical, clinical, and population-level perspectives, the review offers a holistic overview that extends beyond the scope of single-domain reviews.

Nevertheless, several limitations should be acknowledged. First, the analysis was restricted to English-language publications indexed in the Web of Science Core Collection. Although Web of Science is widely recognised for its high-quality citation indexing and is commonly used in bibliometric research, relevant studies indexed exclusively in other databases such as Scopus, PubMed, or CINAHL may not have been captured. This is a particular concern for a field as interdisciplinary as gait research in LBP, where relevant studies may be published in journals not indexed in Web of Science. Second, the keyword-based co-occurrence analysis depends on author-selected terms and may not fully capture nuanced methodological differences across studies. Third, restricting the search to the title field may have excluded potentially relevant studies in which gait-related concepts appeared only in the abstract or author keywords. Fourth, the narrative synthesis was not based on a systematic data extraction or quality appraisal, and the findings should therefore be interpreted as descriptive and conceptual rather than as definitive evidence of causal relationships. Fifth, the bibliometric analysis captures research activity rather than research quality or clinical importance; a high volume of publications on a topic does not necessarily indicate a strong evidence base. Finally, the search date of 22 December 2025 means that the 2025 publication count represents a partial year, and the citation counts for recent years are likely to be underestimated due to citation latency.

Conclusion

This bibliometric and narrative review synthesised publication trends and thematic structures in gait-related research on LBP, demonstrating that the field has evolved into a mature and multidimensional area of inquiry. The steady increase in research output over recent decades reflects a growing recognition of gait as a meaningful indicator of functional impairment and altered movement behaviour in individuals

with LBP, extending beyond traditional pain-centred perspectives.

Across the literature reviewed, gait alterations in LBP are consistently characterised by changes in trunk and lower-limb coordination, neuromuscular control, and movement variability. However, the available evidence does not establish whether these gait alterations precede LBP, develop in response to symptoms, or persist as longer-term adaptations. The increasing use of variability- and stability-focused analyses further highlights a conceptual shift toward examining adaptability and motor flexibility as important components of gait function in this population.

The emergence of clinically oriented research themes underlines the growing integration of gait analysis into assessment and rehabilitation contexts. Gait parameters are increasingly evaluated alongside disability measures and functional outcomes, suggesting their potential value as complementary measures of walking function and rehabilitation outcomes. At the same time, population- and performance-focused research underscores the influence of factors like age, proximal joint contributions, and overall physical capacity on gait behavior, reinforcing the need for a whole-body approach when interpreting gait changes associated with LBP.

Advances in measurement technology—including wearable sensors, computational modelling, and data-driven analytical methods—have expanded the scope of gait research beyond the laboratory, enabling more ecologically valid assessment of walking behaviour. However, the diversity of methodologies and outcome measures identified in this review also points to a lack of consensus that may hinder comparability across studies and slow clinical translation.

Overall, these findings emphasise the need for condition-specific and domain-informed gait assessment frameworks that integrate biomechanical, motor control, variability, and functional performance dimensions. Establishing such frameworks could enhance consistency in future research and facilitate evaluation of the

clinical utility of gait analysis for individuals with LBP.

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Authors' contributions

NM contributed to conceptualization, methodology, investigation, data curation, formal analysis, visualization, and writing – original draft and review/editing. SAB and HM both contributed to supervision, methodology, validation, and writing – review/editing. AA contributed to methodology, validation, and writing – review/editing. ZR contributed to investigation, project administration, and writing – review/editing.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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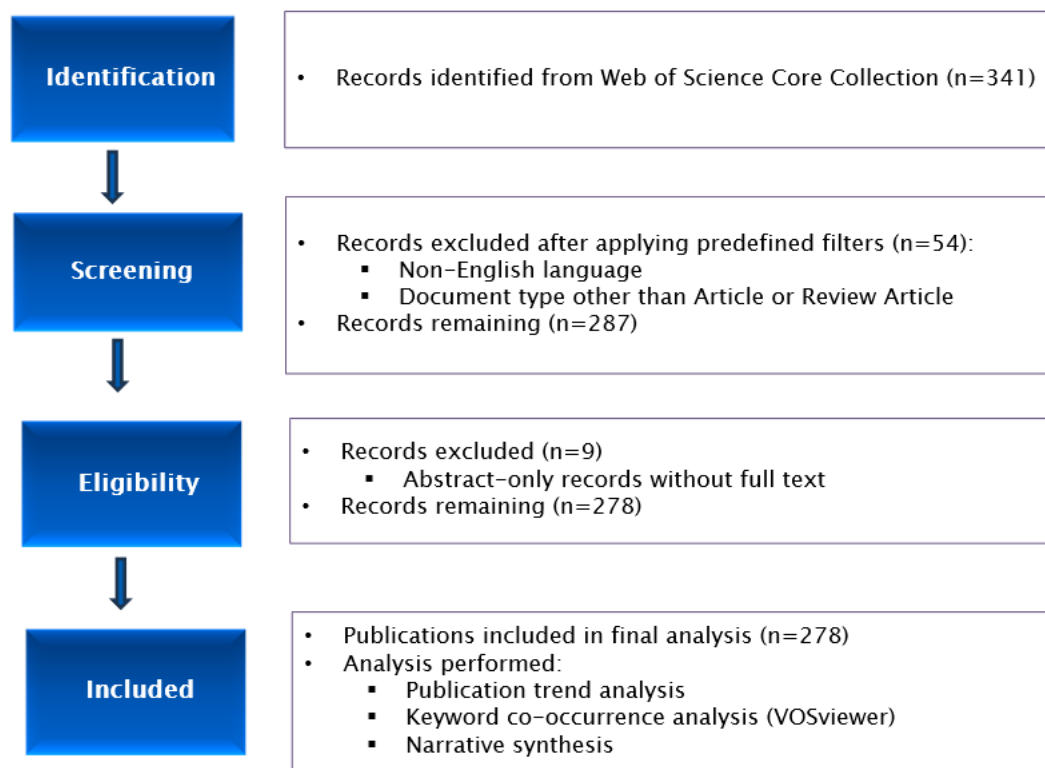


Figure 1. Flow diagram of study identification, screening and inclusion

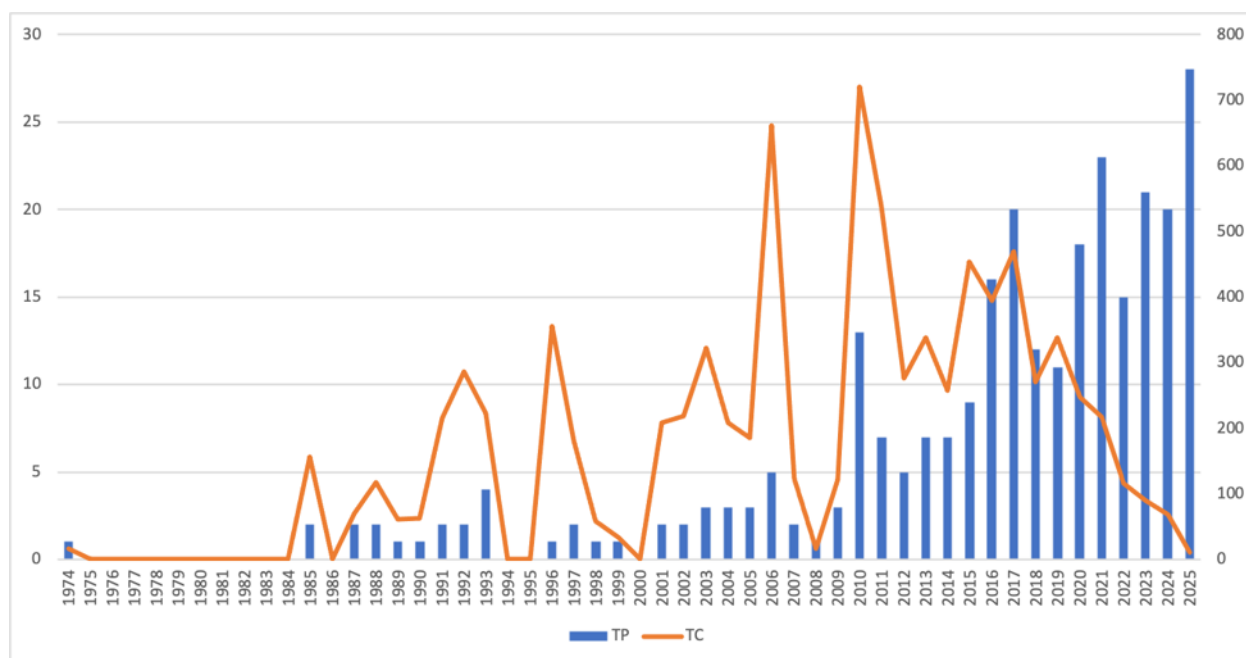


Figure 2. Annual publication and citation trends in gait-related low back pain (LBP) research from 1974 to 2025. TP = total publications; TC = total citations. Note: TC represents annual citations to publications from that year, not cumulative citations.

Table 1. Summary of key gait variables and measurement tools reported in gait-related low back pain research

Gait domain	Key gait variables	Measurement tools
Spatiotemporal parameters	Gait speed, stride length, step length, cadence, stance and swing time	3D motion capture systems, inertial measurement units (IMUs), pressure-sensitive walkways
Kinematics	Trunk, pelvis, hip, knee, and ankle joint angles; segmental range of motion	3D motion capture systems, IMUs
Kinetics	Ground reaction forces, joint moments, loading rates	Force plates, instrumented treadmills
Inter-segmental coordination	Trunk–pelvis coordination, pelvis–lower limb coordination, phase relationships	3D motion capture systems, coordination and phase analysis methods
Gait variability and stability	Stride-to-stride variability, coordination variability, stability indices	Motion capture systems, IMUs, nonlinear and variability analyses
Neuromuscular activity	Muscle activation timing, amplitude, co-contraction	Surface electromyography (EMG)

Note: Table 1 was generated from the narrative synthesis of key primary studies and represents commonly reported variables and tools, not a systematic extraction from all 278 publications.

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