ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

Advances in Gait Assessment in Autism Spectrum Disorder

Jinfeng Li[1,a,*], Xiaoyu Chen[1,b]

[1]Guangdong Provincial Key Laboratory of Development and Education for Special Needs Children, Lingnan Normal University, Zhanjiang, 524048, Guangdong, China
[a]jinfeng.jl@outlook.com, [b]xiaoyu.xc@outlook.com
**Corresponding author*

Abstract: *Autism spectrum disorder (ASD) is frequently accompanied by motor difficulties, including atypical gait, that emerge early and often persist into adulthood. Although gait abnormalities are not part of the core diagnostic criteria, gait offers a detailed, quantifiable window into the ASD motor phenotype that complements standard clinical motor scales. This narrative review summarizes gait characteristics in ASD across spatiotemporal, kinematic, kinetic, variability, symmetry, and dynamic-balance domains, and synthesizes current and emerging assessment approaches, from walkways and three-dimensional motion capture to wearable sensors, markerless video, and mobile brain-body imaging. We propose that further progress depends less on adopting ever more sophisticated instrumentation and more on standardized, ASD-friendly, longitudinal assessment that translates statistical group differences into individually meaningful, clinically interpretable measures.*

Keywords: *Autism Spectrum Disorder, Gait Assessment, Motor Control, Dynamic Balance*

1. Introduction

Gait abnormalities are not a core diagnostic feature of autism spectrum disorder (ASD), yet a substantial body of evidence shows that many individuals with ASD walk differently from their typically developing (TD) peers. Reduced coordination, impaired balance, and atypical gait have been documented from early childhood through adulthood, and a scoping review of 19 studies covering 784 individuals with ASD found motor impairments spanning skills, coordination, balance, agility, strength, and gait across age groups [1]. This persistence distinguishes ASD-related motor difficulty from a simple developmental delay that might be expected to diminish with age. Because walking integrates motor control, dynamic balance, interlimb coordination, and sensory feedback within a repeating cycle, gait offers a more granular window into an individual's motor phenotype than global motor scales, and early work linking gait deviations in ASD to cerebellar and basal ganglia involvement helped establish gait as a distinct area of motor research in this population[2]. Because these deviations are present even in children with no diagnosed orthopedic or neuromuscular condition, gait abnormality in ASD is best understood as part of the broader motor phenotype rather than a secondary or incidental finding.

Quantitative gait assessment adds information that a global motor score or brief visual observation may miss. Two people can walk at similar average speeds while differing in joint motion, consistency between strides, or coordination between limbs. Conversely, a statistically significant difference from typically developing (TD) peers may have little practical significance for an individual. The heterogeneous findings summarized by Lum et al. make this distinction essential: group comparisons describe tendencies, but do not establish a universal ASD gait profile or an individual threshold for impairment[3]. Assessment therefore needs to connect biomechanical detail with functional context.

The aim of this focused narrative review is to examine gait assessment in people with an established ASD diagnosis, emphasizing children and adolescents. This paper summarizes gait characteristics in ASD across spatiotemporal, kinematic, kinetic, variability, symmetry, and dynamic-balance domains, and synthesizes current and emerging assessment approaches, from walkways and three-dimensional motion capture to wearable sensors, markerless video, and mobile brain-body imaging, and discusses challenges and future perspectives.

ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

2. Gait characteristics in ASD and their interpretation

Differences in the timing and spacing of steps provide the clearest starting point for characterizing gait in ASD. A meta-analysis of 18 studies reported wider step width, slower walking speed, and longer gait cycle, stance, and step times, together with greater within-person variability in stride length, stride time, and speed[3]. These findings support measuring both average performance and its consistency. They should be interpreted as tendencies across samples: the direction and magnitude of differences vary with participant characteristics and study methods, and an individual may show only some of these features.

Stride-to-stride variability can reveal differences that are obscured by average values. It describes variation in a specified gait parameter across successive strides, commonly quantified using the standard deviation or coefficient of variation. Manicolo et al. found greater gait variability in children with infantile or atypical autism, with higher variability associated with poorer motor skills and lower variability at older ages[4]. This supports considering gait regularity alongside motor ability. However, an association with age in a cross-sectional sample does not establish how an individual child's gait will develop, and variability alone should not be equated with instability or increased fall risk.

Joint motion and loading provide a complementary explanation of how the walking pattern is produced. Reported findings include reduced ankle or knee range of motion, altered hip joint angles, and differences in net joint moments or push-off mechanics[2]. Walking speed is particularly important when interpreting these measures. Bennett et al. found similar sagittal-plane biomechanics but persistent frontal-plane differences when adolescents with ASD and controls walked at matched speeds[5]. Thus, an apparent group difference may depend on how speed is handled. Comparable forward progression can also coexist with differences in frontal-plane joint mechanics, which are not fully captured by routine timing and distance measures.

Coordination and symmetry describe different aspects of gait and should be interpreted separately. In adolescents with ASD, Bennett et al. reported greater intersegmental coordination variability between the two thighs at both examined speeds, whereas a foot–shank coordination difference occurred only in the matched self-selected-speed condition[6]. Evidence for asymmetry is less consistent: Chester and Calhoun found no significant group differences in spatiotemporal symmetry[7], while Eggleston et al. identified participant-specific asymmetries in joint-angle and ground-reaction-force waveforms[8]. These findings concern different outcomes and are not necessarily contradictory. Similar left and right step lengths do not establish that the two limbs use identical joint mechanics throughout the stride.

Balance during walking requires assessment beyond standing balance or step width alone. Locomotion involves continuous regulation of body motion relative to changing foot support, so broader balance difficulties provide relevant context but cannot substitute for direct gait measures. A recent review found poorer balance performance in children and adolescents with ASD, with substantial heterogeneity and low to very low certainty of evidence[9]. Measures relating center-of-mass position and velocity to the base of support, such as the margin of stability, may add information about dynamic control. Their individual clinical interpretation in ASD, however, remains insufficiently established to justify treating a particular value as a validated marker of impairment.

Taken together, the evidence favors a multidimensional description of gait over a search for one characteristic abnormality. A useful assessment should distinguish walking pace, step-to-step consistency, joint mechanics, and responses to changing demands, while recognizing that each captures only part of locomotor control. This also limits mechanistic interpretation: altered gait can motivate hypotheses about sensory integration or neural control, but biomechanical measurements alone cannot identify a specific neural cause. These distinctions provide the basis for choosing an assessment method that matches the question being asked.

3. Established assessment approaches

Clinical assessment establishes the functional context needed to interpret instrumented gait findings. Observation can identify conspicuous walking patterns, while timed mobility tests and standardized motor assessments describe performance on everyday or structured tasks. For example, the Timed Up and Go test includes rising, walking, turning, and sitting, whereas the Movement Assessment Battery for Children, Second Edition (MABC-2), samples broader motor abilities. A systematic review identified 11 instruments assessing mobility aspects in young people with ASD, but most assessed measurement properties were supported by evidence of low or very low certainty[10]. Such tools remain useful, provided their scope is understood: a composite score cannot specify the joint mechanics or stride-to-stride

ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

consistency responsible for the observed performance.

Electronic walkways offer an accessible approach when the main question concerns walking pace and step organization. Foot contacts yield speed, cadence, step and stride lengths, step width, and stance, swing, and double-support durations; appropriate pressure-sensitive systems can additionally describe plantar loading. Their application in ASD includes the assessment of gait variability and its association with motor skills[4]. Limited preparation and straightforward outputs make walkways attractive for short sessions. However, the recording area restricts the number of consecutive strides, so repeated passes may be needed. Acceleration, deceleration, turning, and incomplete contacts must be handled consistently. These systems describe footfall patterns well but do not provide a complete account of joint kinematics or kinetics.

Three-dimensional motion capture with synchronized force platforms provides the most detailed established laboratory approach to gait mechanics. Cameras track markers placed on anatomical landmarks, allowing biomechanical models to estimate segment movement and joint angles. Force-platform data combined with kinematic data and segment inertial properties support inverse-dynamics estimates of net joint moments and joint power. This makes the approach suitable for questions about propulsion, joint-level compensation, or differences occurring during particular phases of the gait cycle. This approach underlies most of the kinematic and kinetic findings reviewed above[5,8]. Its resource demands and practical limitations, however, are substantial: a dedicated laboratory, calibration, marker placement, and limited ecological validity, all of which are magnified when the participant is a child with ASD who may be sensitive to unfamiliar equipment or setting, and which can limit both the number of children who can be tested and the number of usable trials obtained per child.

Instrumented treadmills extend laboratory assessment to repeated strides and controlled changes in walking conditions. They allow speed to be regulated and, when combined with motion capture, force measurement, or virtual reality, support examination of adaptation to perturbations. Biffi et al. used a dual-belt treadmill and immersive environment to study discrete gait perturbations in children with ASD[11]. Adaptation rates were comparable to those of TD children for many parameters, despite differences in the adaptation pattern. Treadmill results nevertheless require attention to familiarization and cannot be assumed to represent overground walking directly.

Several newer approaches prioritize portability and lower participant burden, with measurement performance depending on the device, outcome, and protocol. Wearable inertial sensors, placed on the limbs, pelvis, or trunk, can estimate stride timing, cadence, speed, and segmental orientation outside a fixed laboratory space; one study used bilateral sensors to characterize age-related differences in gait kinematics in children with ASD[12], and a validation study in individuals with autism found strong sagittal-plane segment-angle waveform correlations with motion capture despite residual angular errors, with less consistent performance in the frontal and transverse planes[13]. A broader pediatric systematic review of 45 wearable-sensor studies likewise reported generally better sagittal-plane kinematic performance[14]. Markerless, camera-based motion capture using pose-estimation algorithms offers a further reduction in equipment and setup time; systematic reviews comparing markerless with marker-based capture report generally favorable spatiotemporal estimates and moderate-to-excellent agreement for selected sagittal-plane hip and knee measures, with weaker and more variable ankle and non-sagittal results[15,16]. However, these reviews do not establish ASD-specific measurement validity, and further validation in children with ASD is needed.

The choice among these approaches should follow the assessment question and the participant's tolerance. An electronic walkway may provide sufficient information about pace or regularity, whereas a question about joint kinetics requires additional biomechanical measurement. A treadmill is valuable when controlled adaptation is the target, but may introduce unnecessary demands for a simple mobility assessment. Sensory preferences, understanding of instructions, and willingness to repeat the task influence the amount and quality of usable data. These practical constraints explain the interest in portable and contact-free methods, while also providing a standard against which their claimed advantages should be judged.

4. Emerging advances in gait assessment

Beyond incremental refinement of existing tools, three developments are reshaping how gait in ASD might be studied in the future. The first extends assessment from the laboratory into real-world settings: wearable sensors and smartphones can, in principle, support repeated or continuous monitoring at home or school, capturing day-to-day variability that a single laboratory session cannot. A systematic review

ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

of smartphone-based gait assessment found moderate-to-strong correlations and variable agreement with reference systems for some parameters, though with substantial heterogeneity across studies[17]; ASD-specific evidence for this kind of free-living monitoring remains limited and should be treated as a priority for future work rather than an established capability.

The second direction enriches the walking task itself, moving beyond simple straight-line walking toward paradigms such as optic-flow manipulation, dual-task walking, and perturbation protocols that better approximate everyday locomotor demands. Mobile brain-body imaging (MoBI) integrates brain recordings with body-motion and behavioral measures during movement. Depending on the protocol, it can combine electroencephalography (EEG), gait kinematics, and electromyography (EMG) to characterize neural and muscle activity alongside gait performance. A MoBI study combining EEG, gait kinematics, and behavioral measures found that typically developing adolescents and young adults had higher visual Go/No-Go task sensitivity during walking than standing, whereas participants with ASD did not show the same improvement, revealing a motor–cognitive interaction not captured by kinematics alone[18]; concurrent EEG and EMG recordings during walking have also been demonstrated outside ASD samples[19], supporting the methodological groundwork for extending such paradigms to ASD populations even though direct evidence in this group remains limited.

The third direction concerns automated analysis: artificial intelligence and machine-learning methods are increasingly used for human pose estimation, gait-event detection, and pattern clustering within markerless and wearable-sensor pipelines, and may reduce processing time or organize complex waveforms into interpretable profiles. This measurement-oriented role should be kept conceptually distinct from AI-based screening or ASD–TD classification, which uses similar gait features for a different purpose and falls outside the scope of this review; a recent study used single-camera markerless pose estimation to quantify gait and then applied the extracted features to ASD–TD classification[20]. The classification component is distinct from the assessment focus of this review.

5. Challenges and future perspectives

Several challenges currently limit how much can be concluded from the ASD gait literature. Participant heterogeneity is foremost: individuals with ASD vary widely in age, sex, body size, intellectual ability, symptom severity, and co-occurring motor disorders, and pediatric gait itself changes across development, as age-related differences have been reported in gait variability[4] and gait kinematics[12]. Studies that do not adequately report or control for these factors risk attributing developmental or clinical variation to ASD itself, and future work should report age, sex, anthropometric characteristics, cognitive level, and walking speed as standard practice, ideally alongside statistical adjustment wherever sample size allows it.

A related problem is the lack of standardized protocols: studies vary in overground versus treadmill walking, self-selected versus fixed speed, the number of trials, and parameter definitions. Speed matching is important when interpreting group differences, and coordination variability may differ between speed conditions[5,6]. Establishing the measurement error associated with a given protocol, as reliability studies of three-dimensional gait analysis have begun to do[21], is equally important for distinguishing genuine change from noise. A consensus-based set of core outcome measures and reporting standards for ASD gait research does not yet exist but would substantially improve comparability across studies.

Feasibility and ecological validity present a second pair of linked problems: laboratory protocols may be burdened by sensory sensitivity, equipment tolerance, and task fatigue, while even a stable, well-characterized laboratory gait pattern may not represent how an individual actually walks at school or at home. Newer technologies such as markerless capture and wearable sensors should not be adopted merely because they are cheaper or more convenient; each requires population- and outcome-specific evidence of validity, reliability, and measurement error in pediatric and ASD populations, an evidence base that remains thinner than for general adult use[14,15]. Interchangeability with a reference system requires separate evaluation of agreement if the methods are intended to substitute for one another. Until such population-specific validation accumulates, newer technologies are best used alongside, rather than in place of, established reference methods.

Looking ahead, the field's progress will likely depend on three shifts: moving from cross-sectional ASD-versus-TD comparisons toward longitudinal designs that track developmental trajectories and intervention response; moving from single-domain biomechanical measurement toward multimodal approaches that combine gait kinematics with EEG and behavioral measures, for which MoBI offers one emerging template[18]; and, most fundamentally, moving from asking only whether a statistically

ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

significant group difference exists toward asking whether that difference exceeds measurement error, relates to daily mobility, and can meaningfully describe an individual's gait phenotype. Achieving this will help translate quantitative gait assessment into a genuine foundation for individualized, assessment-guided intervention.

6. Conclusion

Gait assessment in ASD has moved from clinical observation toward a diverse quantitative toolkit spanning spatiotemporal assessment, three-dimensional kinematics and kinetics, and dynamic stability characterization, revealing differences that are real but heterogeneous and that extend beyond simple averages to variability, symmetry, and coordination. Methodologically, the field now spans wearable sensors, markerless video capture, real-world monitoring, task-enriched multimodal paradigms, and AI-assisted analysis, each trading biomechanical detail against cost and participant burden in a way that matters particularly for individuals with ASD, whose sensory sensitivity and tolerance for equipment shape which approach is actually usable. Future progress will depend less on adopting ever more sophisticated technology and more on building standardized, participant-friendly, and clinically meaningful assessment that can follow individuals with ASD longitudinally and translate statistical differences into measures relevant to their everyday mobility.

Acknowledgements

This work was supported by the Guangdong Philosophy and Social Science Planning Project (GD26YDXZ14), the Medical Scientific Research Foundation of Guangdong Province (B2025536), the Talent Project of Lingnan Normal University (ZL2418), and the Independent Research Project of the Guangdong Provincial Key Laboratory of Development and Education for Special Needs Children (ZL202614).

References

[1] da Silva S H, Felippin M R, de Oliveira Medeiros L, et al. A scoping review of the motor impairments in autism spectrum disorder[J]. Neuroscience and Biobehavioral Reviews, 2025, 169: 106002.
[2] Kindregan D, Gallagher L, Gormley J. Gait deviations in children with autism spectrum disorders: a review[J]. Autism research and treatment, 2015, 2015: 741480.
[3] Lum J A G, Shandley K, Albein-Urios N, et al. Meta-Analysis Reveals Gait Anomalies in Autism[J]. Autism Research, 2021, 14(4): 733-747.
[4] Manicolo O, Brotzmann M, Hagmann-von Arx P, et al. Gait in children with infantile/atypical autism: Age-dependent decrease in gait variability and associations with motor skills[J]. European journal of paediatric neurology: EJPN: official journal of the European Paediatric Neurology Society, 2019, 23(1): 117-125.
[5] Bennett H J, Ringleb S I, Bobzien J, et al. Walking lower extremity biomechanics of adolescents with autism spectrum disorder[J]. Journal of Biomechanics, 2021, 119: 110332.
[6] Bennett H J, Jones T, Valenzuela K A, et al. Inter and intra-limb coordination variability during walking in adolescents with autism spectrum disorder[J]. Clinical Biomechanics (Bristol, Avon), 2021, 89: 105474.
[7] Chester V L, Calhoun M. Gait symmetry in children with autism[J]. Autism research and treatment, 2012, 2012: 576478.
[8] Eggleston J D, Harry J R, Hickman R A, et al. Analysis of gait symmetry during over-ground walking in children with autism spectrum disorder[J]. Gait & Posture, 2017, 55: 162-166.
[9] Martín-Díaz P, Carratalá-Tejada M, Navarro-López V, et al. Static and dynamic balance in children and adolescents with autism spectrum disorder compared with typically developing peers: a systematic review and meta-analysis[J]. European Journal of Pediatrics, 2026, 185(4): 209.
[10] de Lima A F B, Fernandes A C, Soares A A R, et al. Instruments assessing mobility of children and adolescents with autism spectrum disorder: A systematic review and decision map[J]. Developmental Medicine and Child Neurology, 2026, 68(8): 1049-1062.
[11] Biffi E, Costantini C, Ceccarelli S B, et al. Gait Pattern and Motor Performance During Discrete Gait Perturbation in Children With Autism Spectrum Disorders[J]. Frontiers in psychology, 2018, 9: 2530.
[12] Li Y, Koldenhoven R M, Liu T, et al. Age-related gait development in children with autism spectrum

ISSN 2618-1576 Vol. 8, Issue 4: 49-54, DOI: 10.25236/FSR.2026.080408

disorder[J]. Gait & Posture, 2021, 84: 260-266.
[13] Luginsland L A, Barrett K B, Bennett H J. Examination of inertial measurement units to evaluate lower body segmental angles in persons with autism[J]. Journal of Biomechanics, 2026, 197: 113172.
[14] Bavan L, Ng K, Gardner R, et al. Wearable inertial sensors for paediatric gait assessment: A systematic review[J]. Gait & Posture, 2026, 128: 110188.
[15] Scataglini S, Abts E, Van Bocxlaer C, et al. Accuracy, validity, and reliability of markerless camera-based 3D motion capture systems versus marker-based 3D motion capture systems in gait analysis: A systematic review and meta-analysis[J]. Sensors (Basel, Switzerland), 2024, 24(11): 3686.
[16] Cheng X, Jiao Y, Meiring R M, et al. Reliability and validity of current computer vision based motion capture systems in gait analysis: A systematic review[J]. Gait & Posture, 2025, 120: 150-160.
[17] Bea T, Chaabene H, Freitag C W, et al. Psychometric characteristics of smartphone-based gait analyses in chronic health conditions: A systematic review[J]. Journal of Functional Morphology and Kinesiology, 2025, 10(2): 133.
[18] Nicklas P R, Cruz L N, Terilli C, et al. A symphony of functioning: exploring the interplay of cognition, movement, and visual demands in adolescents on the autism spectrum using mobile brain-body imaging (MoBI)[J]. Journal of Neurodevelopmental Disorders, 2026, 18(1): 13.
[19] Peterson S M, Ferris D P. Group-level cortical and muscular connectivity during perturbations to walking and standing balance[J]. NeuroImage, 2019, 198: 93-103.
[20] Ganai U J, Ratne A, Bhushan B, et al. Early detection of autism spectrum disorder: gait deviations and machine learning[J]. Scientific Reports, 2025, 15(1): 873.
[21] Horsak B, Kranzl A, Slijepcevic D, et al. Test-retest reliability of spatiotemporal, kinematic, and kinetic measures in marker-based 3D gait analysis: A systematic review[J]. Gait & Posture, 2026, 130: 110270.