

EARLY DETECTION OF GAIT PATTERNS IN CHILDREN WITH AUTISM SPECTRUM DISORDER: A SYSTEMATIC REVIEW

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DOI: <https://doi.org/10.5281/zenodo.18740044>

Keywords

Autism, Gait patterns, TD, Machine Learning algorithms, Deep Learning algorithms, Type of dataset

Article History

Received: 24 December 2025

Accepted: 08 February 2026

Published: 23 February 2026

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Abstract

Autism Spectrum Disorder become the most emerging challenge for practitioners nowadays. Children with autism face challenges in communication, lack of interaction with other children, having repetitive behavior, sensory impairments, and motor impairments. Beside behavioral and sensory impairments motor impairments have been ignored by the most of practitioners. The study reviewed that children with autism have found gait deviations due to reduced stride length, variance in step width, high cadence. Four online data bases were searched using keywords "autism, gait, machine learning, deep learning algorithms". The purpose of this study was to review previous literature about gait deviations in children with autism spectrum disorder. The study based on selection criteria, sample sizes which include participant type (ASD & TD), sample size, average age in years, gait assessment techniques, gait features and classification algorithms such as logistic regression, Support Vector Machine (SVM), K-Nearest Neighbor (KNN), Naïve Bays, Artificial Neural Network (ANN), Structure-Aware Multi-Layer Perceptron (SA+MLP), SA and Linear Discriminant Analysis (LDA), Principal Component Analysis (PCA) and MLP and so on. But high accuracy was observed at CNN 95%, PCA and MLP 95.6% accuracy, then at SA and LDA 91% accuracy was found. It was concluded that children with ASD found reduced ankle and knee motion during walk/gait, have asymmetrical walk as compared to atypical children, decreases stability during walk. Further, there is need to conduct the study based on markerless based system, larger dataset required for minimizing error rate and gain high accuracy with more advanced AI algorithms.

1. Introduction and Background

Autism Spectrum disorder is neurodevelopmental condition which impair the brain development in early childhood and affecting different cognitive, emotional, social, behavioral and motor functions.

In Autism children faces social isolation, same behavioral patterns, lack of coordination with other children of same age group, speech problems, and sensory impairments. Likewise, in other disorders such as Attention-

Deficit/Hyperactivity Disorder (ADHD), Intellectual disability and Mental Retardation (MR), children are found with inattention or impulsivity, lack of self-control, face challenges in behavioral functions and also found abnormal motor functions like abnormal hand movements, trunk movement, and unusual walking patterns [1]. Although motor impairments mostly ignored in children with ASD which affect the quality life and social growth [2]. These motor impairments applies at early stage in children with autism spectrum disorder (ASD), and become more prominent with growing age [3, 4] and with time they become ubiquitous feature the autism spectrum disorder. Among several motor impairments such eye and gesture impairments, eye -hand coordination, abnormal hand movement, unusual gait patterns are the most common found in children with autism [5, 6, 7, 8]. Many gait stereotypies, including pacing, jumping, hopping, skipping, and spinning, have been shown to be exhibited frequently in children with ASD, and it has been postulated that these can also be viewed as restrictive and repetitive behavior [9]. Gait abnormalities can simply be viewed as a departure from normal walking patterns and can include, but are not limited to, stereotypies listed above. The manner or style of walking or gait can be stated to be method of locomotion wherein there is cerebral regulation of reciprocal motion of the lower limb, functioning in conjunction to afford both propulsion and support [10]. Abnormalities in movement patterns have also been detected in children with ASD as far back as 1943, where notices were made about clumsy gait and motor behavior in children with ASD by Kanner [11]. Recently, Ghaziuddin and Butler have also found that children with ASD had poor coordination relative to those with Asperger's disorder [12]. Many researchers have also attempted to investigate motor coordination problems in children with ASD and a recent one, carried out by Fournier et al, provided support to earlier findings and stated that children diagnosed with ASD are less coordinated and have fewer motor skills [13].

The introduction covers about autism with their symptoms appeared in children, different

impairments/ disorder that have been diagnosed such as behavioral impairments, sensory impairments and motor impairments. Besides other impairments diagnosed, in motor impairments is most important factor which is gait patterns that have been ignored due to lack of advanced techniques. Therefore, the study will cover the inclusion criteria and exclusion criteria on the basis of techniques, type of participants, age of participants, and conformed cases of autism, type of study either marker based or mar-less based and possibility of other comorbidities.

2. Results and Discussions

2.1. Search Strategy

A comprehensive electronic search has been performed for abnormal gait detection in children with Autism Spectrum Disorder (ASD) through online databases such as Google Scholar, PubMed, Research Gate, and Science Direct. The database covers the articles from 1998 to 2024 on gait detection in children with ASD. The interdisciplinary research targeted the articles related to biomedical engineering, neurodevelopmental disorders, and biomechanics with keywords like "gait patterns" OR, "gait detection" OR "gait identification", OR "walking patterns" OR "gait analysis" AND "autism spectrum disorder" OR "autism" OR "ASD" OR "autistic child" OR "autism children" AND key features for gait like "Spatiotemporal" OR "kinetic parameters" OR "kinematic parameters" OR "stride length, stride width, cadence as spatiotemporal measures" AND "machine learning and deep learning algorithms classification accuracy for gait detection. Beside this search strategy, this study also documented the exclusion criteria like; ASD children below 3years age, toe walking, treadmill walking, Comorbidity disorders, inappropriate groups& variables well defined in selection criteria.

2.2. Selection Criteria

This section covers the inclusion and exclusion criteria based on data type which includes spatiotemporal, kinetic and kinematic parameters, biomarker or biomarkerless, toe walking, treadmill walking, walking patterns, children

diagnosed with autism or other disorders. It also covers online database/sources to retrieve relevant articles for review from different search engines

such as; Google Scholar, PubMed, Research Gate, and Science Direct as shown in following flow chart in Figure.1.

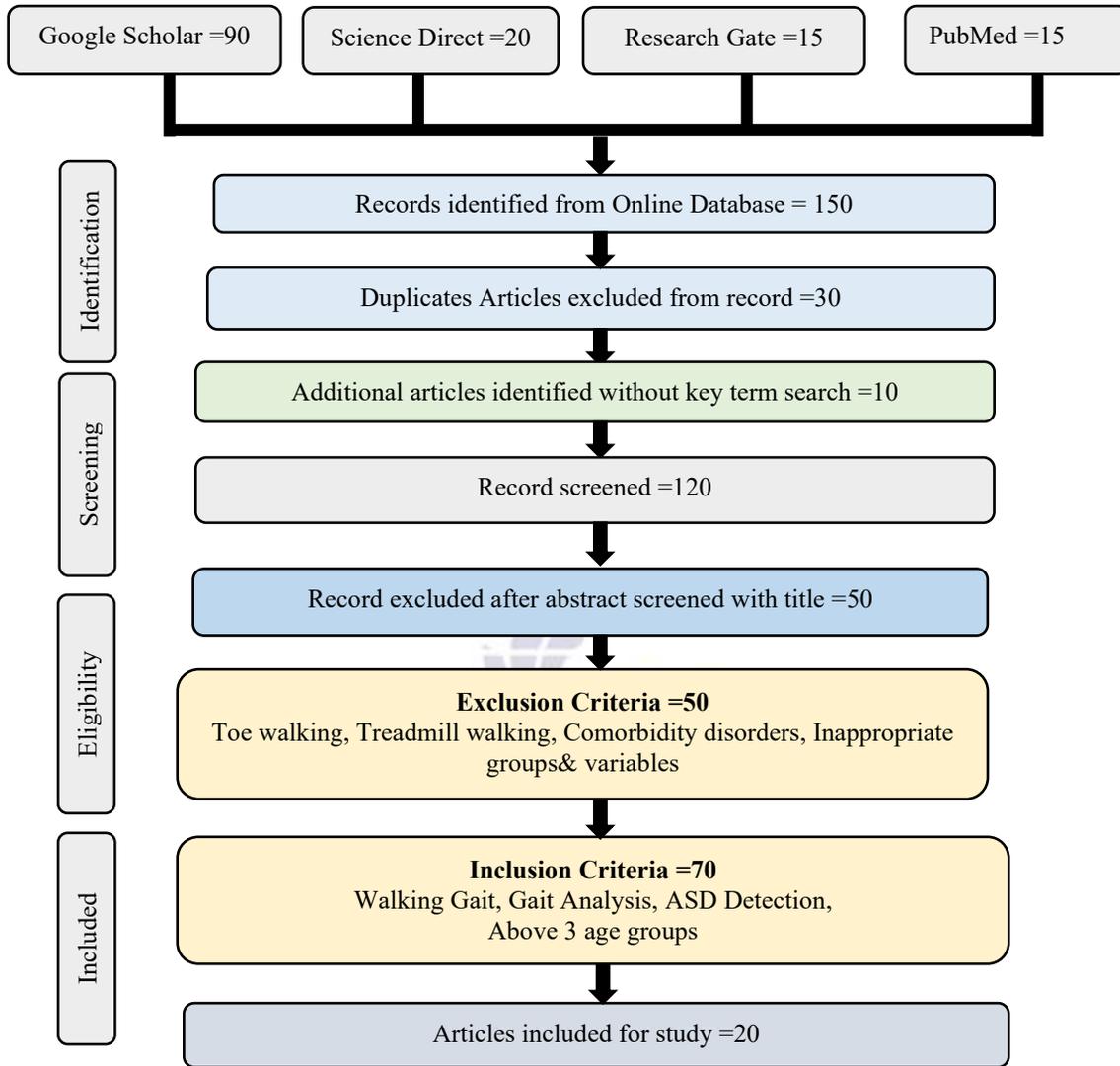


Figure.1. The inclusion and exclusion criteria for early detection of Gait Patterns in children with ASD

2.3. Sample sizes

The purpose of collecting sample sizes was to diagnose unusual walking patterns in children with autism and compare these asymmetrical gait patterns with normal children. Table.1. is about the detailed literature recorded on sample sizes of ASD and atypical children. It was observed that maximum collected data of autism spectrum children and controlled children is 68 and 50 respectively [16], whereas another study have

reported 23 ASD and 30 AD children [17]. Following reported sample sizes have been collected through different gait techniques such as Kinect sensors, depth sensors, RGB camera, Vicon 3D motion system and so on [14,15, 16, 17, 18, 19, 20, 21 and 22]. It was also found that literature reported about marker based and marker-less [17] with age matched groups without any variation in age groups. The purpose of collecting sample sizes was to diagnose unusual walking patterns in

children with autism and compare these asymmetrical gait patterns with normal children.

Table.1. Represents the Literature Recorded on Participants Group, Recorded Sample Size and

Literature Reported	Participants Group	Recorded Sample Size	Recorded Age (Year)/Mean (SD)
U. J. Ganai, et al. [14]	ASD	32	5.97yrs
	TD	29	4.86
S. A. Yazdi, et al. [15]	ASD	50	5-15 yrs
	Healthy	50	
B. Henderson, et al.[16]	ASD	68	4-14 yrs
	TD	50	
Nur Khalidah Zakariaa, et al. [17]	ASD	23	5 to 12 yrs
	TD	30	
Abdulrahman A et al. [18]	ASD	50	4-12yrs
	TD	50	
Calhoun et al. [19]	ASD	34	5-9 yrs
Hasan et al. [20]	ASD	60	4-12yrs
Hasan et al[21]	ASD	60	4-12yrs
Hasan et al. [22]	ASD	60	4-12yrs
Che Zawiyah et al. [23]	ASD	30	8.63
	Control	30	9.52 yrs
Xinye Wua et al. [30]	ASD	11	8-17yrs
	TD	11	

2.4. Gait Assessment Techniques

There are so many the gait assessment techniques that have been utilized some of them have been categorized in three ways such as sensor based, marker based and marker-less or combination of above mentioned categories in this review. Gait patterns have been monetized through portable or smart sensor based system in a controlled environment. However, for sensor based techniques results found limited due to resolution varies with distance. In marker based study 3D marker trajectories appeared which is only possible to fix the correct marker positions on participant’s body with fitted clothing for data acquisition. Due to limitation the system mostly incorporated in laboratory and is expensive to implement. On the

other hand, marker-less system was cost efficient, video based analysis of gait was possible through this technique and have more accuracy in comparison with marker based system [24]. Based on these three categories one common application of sensor-based technique used pressure mat. Pressure mat was an electronic walkway with pressure sensors placed in the horizontal direction grid. The sensor mat is used to retrieve data through monitoring of gait problems owing to lack of stability, balance, and coordination. For example, there is GAITRite, a pressure mat available in the market used by researchers in their studies as discussed in [25, 26, and 27]. Other prominent sensor-based that is commonly used is a force plate [28]. At the same time, a used shoe

insoles with capacitive sensors to determine plantar distribution of pressure for children with ASD is used [20]. The study has shown that participants walked on force instrumented treadmill at speed of 1.1 meter per second-1.2 meter per second for about five minutes to check the knee muscular strength. It was observed that the participants with autism found unique patterns in lower limb with reduced stride length, variance in stride and also greater ground reaction force (GRF) of about (p=0.03) during walk. [30]

Reported the behavioral and cognitive responses of autistic children. The study found that psychological impact on cognitive functions could be decoded through psychological movement patterns using traditional Machine learning techniques in children with autism. The following Table.2. Is the illustration of detailed literature about participants type, age, approach on which review is conducted, gait techniques, gait classification algorithms and results obtained in the form of accuracy.

Table.2. Summary of Gait Techniques, Gait Classification Methods, Participant’s Type, and Results

Literature Reported	Participants Group	Known Sample Size	Recorded Age (Year)/Mean (SD)	Gait Technique	Algorithms	Results
U. J. Ganai, et al. [14]	ASD TD	32 29	5.97 4.86	RGB camera	Logistic Regression	Accuracy 0.82, Logistic Regression
S. A. Yazdi, et al. [15]	ASD Healthy	50 50	5-15 yrs	Kinect sensor.	k-nearest neighbors, and ensemble classifier	Accuracy 87%,
B. Henderson, et al.[16]	ASD TD	68 50	4-14	Gait Energy Images (GEI)	PCA, MLP, CNN	Accuracy of 95.56% on 100 subjects at CNN and accuracy of 80% on 20 subjects
Nur Khalidah Zakariaa, et al. [17]	ASD TD	23 30	5-12yrs	Depth sensor	SVM, ANN, Naïve Bayes	Accuracy 94.22%
Al-Jubouri et al. [18]	ASD TD	50 50	4-12yrs	Kinect Sensor	PCA MLP	Accuracy 95%
Calhoun et al. [19]	ASD	34	5-9yrs	Motion capture camera	PCA	Accuracy 81%

Hasan et al. [20]	ASD	60	4-12yrs	Force sensor	SA LDA	Accuracy 91.7%
Hasan et al [21]	ASD	60	4-12yrs	Motion-camera	SA+MLP	Accuracy - 91.7%
Hasan et al. [22]	ASD	60	4-12yrs	Motion-camera, force-plate	SA	ASD children have lower push rate
Che Zawiyah et al. [23]	ASD Control	30 30	8.63 9.52yrs	3D motion analysis system	SWDA, ANN	Accuracy 91.7%,

2.5. Gait Features Detection

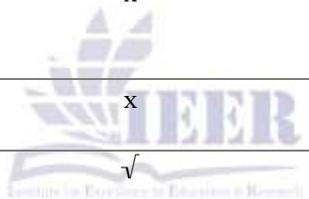
In this section, gait features have been discussed based on gait assessment tools. Gait features have been extracted on the basis of kinetic parameters, kinematic parameters and spatiotemporal parameters. Kinetic parameters involved the forces which causes motion in body. [15, 31, 32] are the studies to investigate body joints, angles and positions in ASD children. It was observed that children with autism have reduced hip flexor movements as compared to healthy children. Whereas, kinematic parameters involved motion without forces, such as speed, velocity, angular

velocity, and acceleration. Meanwhile spatiotemporal parameters involved time, and length, such as stride length, stride width and cadence. Therefore, it was observed that these kinematic, spatiotemporal and kinetic parameters used to analyze variance in gait patterns in ASD children while adding other causing forces in 3D motion system like gravity, ground reaction forces (GRF) to compute lower body movements, body joints and their forces as reported in [33, 20, 34]. In Table.3. Gait features have been reported in detail based on variance in stride width, stride length and reduced cadence [25, 35, and 26].

Table.3. Summary of Gait Features based on Marker-based Gait techniques to Detect Gait Patterns in ASD children

Reported Literature	Gait Technique		Gait Features	
	Sensor Based	Spatiotemporal Parameters	Kinematic Parameters	Kinetic Parameters
S. A. Yazdi et al. [15]	(√)	Cadence, stride length, stride width, Stride time	Hip flexor movements, hip angles	Ground Reaction Forces, body joints, body angles
Hasan C et al. [21]	√	x	x	√
C.-S. Yang et al. [26]	√	√	x	x

J. D. Eggleston, et al. [28]	√	x	x	√
M. Calhoun, et al. [31]	√	√	√	√
D. Ambrosini, et al. [32]	√	√	√	√
M. Calhoun, et al. [33]	√	√	√	√
J. S. Dufek, et al. [34]	√	√	√	√
N.J. Rinehart et al. [35]	√	√	x	x
V. L. Chester et al. [36]	-	√	x	x
Nayate, et al. [37]	√	√	x	x
B.-O. Lim, et al. [38]	√	√	x	x
J. D. Eggleston et al. [39]	√	x	√	√
J. S. Dufek et al. [40]	√	x	√	√
O. Manicolo, et al. [41]	√	√	x	x
S. Morrison, et al. [42]	√	√	x	x
Z. C. Hasan, et al. [43]	√	x	x	√
J. Pauk, et al. [44]	√	√	√	√



Based on above discussed gait features in Table.3, it was easy to find variance in gait patterns were using different machine learning and deep learning algorithms with high accuracy. Next section will cover the classification algorithms for variance in gait based on spatiotemporal, kinematic and kinetic parameters.

2.6. Gait Classification Algorithms

In this section different classification approaches have been discussed based on spatiotemporal, kinematic and kinetic parameters to distinguish between pathological walking patterns and normal

walking patterns in children with autism and normal children. To handle large dataset for gait patterns detection, it is important to select the correct classification algorithms. The most of studies have been conducted between the ASD and TD children under the age group of 4-15 years. To identify unusual walking patterns between 32 ASD and 29 TD children logistic regression has been applied with accuracy of 82% [14]. Another was conducted on KNN and ensembling algorithms with accuracy of 87% while using kinetic sensor between 50 ASD children and 50 healthy children [15]. In [16, 19, and 18] the

study was conducted among the ASD children and TD children with age group of 5 to 12 years. It was observed that 95% accuracy was obtained at CNN, PCA and MLP algorithms, and at PCA 81% accuracy, 83% sensitivity and 78% specificity was obtained whereas at MPL PCA 95% accuracy obtained. [17] Have used SVM, Naïve Bays and ANN to find variance in stride length, stride width and high cadence between 23 ASD and 30 TD children with 94.22% accuracy, 94.49% sensitivity and 93.93% specificity. At the same time in other researches it has been shown that at SA, SA and MLP, SA and LDA algorithms, accuracy of 91.7%, specificity of 90% and sensitivity of 93.3% achieved and was also observed that children with autism were found with lower push rate [20, 21 and 22]. Che Zawayah studied to find gait patterns on kinetic features and kinematic features using SWDA and ANN algorithms to get accuracy of 91.7%, 93.3% sensitivity, and 90.0% specificity among 30 ASD children and 30 controlled children [23]. Based on these classifiers it was seen that ASD children have high cadence, reduced stride length, and high stride width as compare to atypical children.

3. Conclusion

Integration of results highlights the complexity of the issue of gait dysfunction in children with ASD. Some features show permanent divergence from normal standards, while inconsistencies are present among various studies. Differences in study procedure, subjects, and small sample sizes are responsible for inconsistencies. Even diverse research methodologies are capable of yielding a wide array of data on the complex task of gait function, but there is a great need for thoughtful study procedure design. The literature was found on sample size, gait techniques either marker-based or markerless based, extracted features such as stride length, stride width, cadence, body positions and joint angles, stride time and speed were considered to find asymmetrical gait with autistic children. It was concluded that high accuracy obtained at CNN, SA and MLP, SA and LDA, MLP with PCA algorithms. It was also found that most of studies were conducted on marker-based. Therefore, the study reviewed that

there is need to develop markerless based system to find gait deviations in an uncontrolled environment. It was also found that there is need of larger sample size of ASD children to get high accuracy.

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