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Systematic Review

The Urgent Need for Neuroscience Research to Consider Culture when Assessing the Development of Gait in Autistic Children: A Scoping Review

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Abstract

Background: Over the last decade, there has been a steady increase in the number of children diagnosed with autism spectrum disorder (ASD) on a global scale, impacting all racial and cultural groups. This increase in the diagnostic rate has prompted investigation into a myriad of factors that may serve as early signs of ASD. One of these factors includes the biomechanics of gait, or the manner of walking. Although ASD is a spectrum, many autistic children experience differences in gross motor function, including gait. It has been documented that gait is also impacted by racial and cultural background. Given that ASD is equally prevalent across all cultural backgrounds, it is urgent that studies assessing gait in autistic children consider the impact of cultural factors on children's development of gait. The purpose of the present scoping review was to assess whether recent empirical research studies focusing on gait in autistic children have taken culture into account. **Methods**: To do so, we conducted a scoping review following PRISMA guidelines using a keyword searching with the terms *autism*, OR *autism spectrum disorder*, OR *ASD*, OR *autis*, AND *gait* OR *walking* in the following databases: CINAHL, ERIC (EBSCO), Medline, ProQuest Nursing & Allied Health Source, PsychInfo, PubMed, and Scopus. Articles were considered for review if they met all six of the following inclusionary criteria: (1) included participants with a diagnosis of autism spectrum disorder (ASD), (2) directly measured gait or walking, (3) the article was a primary study, (4) the article was written in English, (5) participants included children up to age 18, and (6) the article was published between 2014 and 2022. **Results**: A total of 43 articles met eligibility criteria but none of the articles took culture into account in the data analysis process. **Conclusions**: There is an urgent need for neuroscience research to consider cultural factors when assessing gait characteristics of autistic children. This would allow for more culturally responsive and equitable assessment and intervention planning for all autistic children.

Keywords: culture; gait; autism; biomechanics; children

1. Introduction

Autism spectrum disorder (ASD) has steadily been on the rise, now impacting 1 in 100 children worldwide [1]. ASD is a neurodevelopmental disorder, with specific autistic characteristics presenting themselves uniquely in every autistic child. Although autism is a spectrum, many autistic children present with differences in social communication, restrictive and repetitive behaviors/interests, sensory processing, as well as gross motor skills, in comparison to neurotypical peers [2–4]. Given the steady rise in autism prevalence, investigations have been undertaken to identify early signs of autism in order to provide early assessment and intervention, which has the potential to result in increased quality of life for all autistic children.

Differences in the development of motor skills may serve as an early diagnostic indicator for ASD [5]. For example, early signs of gross motor delays and poor postural control have been posited to indicate neurodevelopmental disruption in children with ASD [6–11]. Poor postural control in infants can lead to delays in crawling and later walking, as postural stability is essential to maintain an upright balance over one's base of support [12]. Importantly, these motor differences emerge before a child with ASD says their first words [7], which are usually parents' primary area of reported concern [13]. In fact, parents who are first concerned with motor difficulties, rather than language, seek professional help, and subsequently, an ASD diagnosis, sooner [14].

With the early diagnostic value of gross motor skills in mind, many recent studies have been devoted to assessing the biomechanics of gait, or the manner of walking, in autistic children. Traditionally, the terms "kinematics" and "kinetics" have been used to study and describe gait patterns. Kinematics refers to the study of motion, including considerations of space and time. The kinematic analysis of gait describes the linear and angular displacements, such as stride or step length, step width, velocity, and acceleration of motion. Kinetic parameters focus on forces in the production of movement in the gait cycle.

Gait variations between autistic children and neurotypical peers have been previously explored utilizing both kinematic and kinetic parameters. Some notable differences have been observed in the gait patterns of autistic children. The most prevalent findings in these studies are increased step width and, debatably, a decrease in both step length and stride length. While some studies have [15] found longer stance phases and shorter stride lengths, others [16] found that stride length in children with ASD is higher at a given cadence compared with neurotypical controls. The same pattern of findings have been shown when kinematic parameter cadence was assessed. While some studies found kinematic parameter cadence to be higher in autistic children [17], other studies [18] reported it to be lower in the ASD group, whereas others found no significant difference between ASD and neurotypical groups [19,20].

Velocity, joint motion, angles, and range of motion also have been explored when assessing gait in autistic walkers. Although many studies have not found any significant difference in velocities between ASD and comparison groups [16,20,21], one study reported that it was significantly reduced in the ASD group [18]. Several studies have investigated joint motion and angles at specific points in the gait cycle. Nobile *et al*. [22] reported increased ankle dorsiflexion at toe-off. Vilensky *et al*. [15] found no significant differences at toe-off but reduced dorsiflexion at heel strike in children with ASD. Therefore, it is currently difficult to discern whether significant changes occur at the ankle joint during the gait cycle in autistic children. Two studies have shown that autistic children have a reduced range of motion with a decreased flexion-extension at the knee during toe-off [15,22], but there was no consensus at the hip joint. Nobile *et al*. [22] showed that autistic children have a reduced hip range of motion, but Vilensky *et al*. [15] showed an increase in hip flexion in autistic children. Thus, overall, findings in kinematic parameters over the gait cycle in autistic children have not been conclusive, with much variability, as is expected given that autism is a spectrum.

Only a few studies have investigated kinetic parameters in ASD, demonstrating several parameters to differ between autistic children and their neurotypical peers. Ambrosini *et al*. [23] reported relatively typical ground reaction forces in autistic children but a reduced second vertical peak, which refers to the ground reaction force in the terminal stance phase. Calhoun *et al*. [17] found that autistic children have reduced peak plantar flexion moments at the ankle. All other ankle kinetic parameters seemed to be within the typical range. No changes were noted in knee joint kinetics, but a significant alteration was found in hip joint kinematics, with the ASD group displaying decreased peak hip flexor moments and increased hip flexion angles. This may imply weakness in the hip flexor muscles, as they are unable to generate the same amount of force as those that neurotypical controls can, and the increased angles suggest a weakness or lack of control in the hip flexor muscles. These results strongly indicate that further investigation of muscle activity in autistic children, as compared with that in neurotypical children, is necessary.

To further complicate interpretations of the variability of kinematic and kinetic findings in autistic gait, the aforementioned gait studies have been conducted with predominantly Western and White individuals, even though cultural and racial background have been shown to impact gait patterns [24–27]. This issue is not only present in the literature assessing gait differences in autistic individuals, but it is present globally, indicating that, in general, much less is known about gait of non-White and non-Western individuals [27]. We take culture to broadly mean the customs, practices, and background of individuals belonging to a specific social group [28]. The few studies that have been conducted with non-White and non-Western individuals do demonstrate that culture and other sociocultural factors impact gait. For example, cultural differences have been shown to impact stride length [24,29], walking speed [27,29] and in general, childrearing practices impact walking milestones and gait patterns [26]. Despite these clearly observed cultural differences, gait parameters obtained from White and Western populations are used globally to make clinical judgments and recommendations.

To understand the early neurobiological factors that impact how gait develops in autistic walkers, and, ultimately, in order to make services more equitable and culturally relevant, it is necessary to undertake gait research on autistic children from diverse cultural backgrounds. The purpose of the present study was to review the recent literature investigating gait patterns of autistic children and whether any studies have considered cultural factors, and to describe how culture was assessed in studies that took culture into account. We assessed each eligible article for cultural factors, which have been broadly defined to mean the customs, practices, and background of individuals belonging to a specific social group, including ethnicity and socioeconomic status [28].

2. Materials and Methods

Identification and selection of research articles for the present review were conducted following the Arksey and O'Malley framework [30] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [31] between October and November 2022. A keyword search with the terms *autism*, OR *autism spectrum disorder*, OR *ASD*, OR *autis*, AND *gait* OR *walking* was used to search the following databases: CINAHL, ERIC (EBSCO), Medline, ProQuest Nursing & Allied Health Source, PsychInfo, PubMed, and Scopus. Articles were considered for review if they met all six of the following inclusionary criteria: (1) included participants with a diagnosis of autism spectrum disorder (ASD), (2) directly measured gait or walking, (3) the article was a primary study, (4) the article was written in English, (5) participants included children up to age 18, and (6) the article was published between 2014 and 2022. Articles published prior to 2014 were excluded due to the change in the diagnostic criteria of autism spectrum disorder in May of 2013 when the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders [DSM-5; 2] took effect. This was done in an effort to ensure that the criteria used to diagnose autism was uniform across all participants in the selected articles and to include articles published within the past 10 years. However, articles published after 2013 in which the DSM-5 was not used to confirm ASD diagnosis were retained because many of the eligible articles were published outside of the United States and the DSM criteria would not necessarily be used in research studies published in countries other than the United States. Thus, we opted to retain those articles in an effort not to penalize research from other countries, especially when the focus of the scoping review is to assess whether cultural factors were considered. Diagnostic criteria used in each article are listed in Table 1 (Ref. [32–74]). Because we aimed to only assess articles where gait/walking was assessed directly, articles that were review articles, meta-analyses or feasibility studies were excluded from the present review. Therefore, only primary empirical research articles were used. Please refer to Table 2 in the Appendix for an example of a full electronic search strategy.

The titles and abstracts of the articles identified through the keyword search were screened using the inclusionary and exclusionary criteria listed above. A checklist including the 6 inclusionary criteria was completed for each article. Articles which met the inclusionary criteria were retrieved for the evaluation of the full text. The full text evaluation included thoroughly reviewing the method and the results section of each article and specifically assessing available information about participant demographics. We specifically focused on whether any cultural factors were provided, including: race, ethnicity, country of origin, socioeconomic status or any additional factors which would speak to participants' cultural background. If cultural factors were provided, we marked whether or not they were taken into account in the data analysis process. Two graduate research assistants conducted the database searches, screened all titles and abstracts, and screened the full text of the relevant articles. One graduate research assistant screened the first half of the articles, while the other graduate research assistant screened the second half of the articles. Inter-rater reliability coding was conducted by having the graduate research assistants blindly code 25% of each other's list of articles. This reached 100% agreement.

3. Results

Across the seven databases, the keyword search resulted in a total of 239 articles. Of those, 144 articles were removed due to duplication, leaving 95 articles to be screened. After abstract and title screening, a total of 49 articles were removed because they did not meet the aforementioned inclusionary criteria. One article was not able to be retrieved for full text examination, an additional article was removed upon full text examination because it did not meet the age range criteria, and another paper was removed because it was a conference proceeding. Thus, a total of 43 articles were reviewed for the present study. Please refer to Fig. 1 for the article selection process.

Table 1 summarizes the findings. Of the 43 articles that met eligibility criteria, one was published in 2014, two were published in 2015, two were published in 2016, seven were published in 2017, seven were published in 2018, two were published in 2019, seven were published in 2020, nine were published in 2021, and six were published in 2022. The eligible articles included children ranging from toddlers at 19 months to 17-year-olds, with the majority of the articles focused on school-age children.

Of the 43 articles, none took into account culture when assessing gait in autistic children. For the purposes of this scoping review, any report of the participants' race, ethnicity, socioeconomic status, country of origin, or cultural identity that was factored into the data analysis would have been coded as taking culture into consideration. Even with this broad estimate of culture, not one single study included in this scoping review considered culture in its analytical interpretations. One study [39] collected information on children's socioeconomic status, this information was not taken into account during the data analysis process. Participant socioeconomic status was not reported in any other article.

4. Discussion

The goal of the present review was to assess whether studies investigating gait differences in autistic children took culture into account given that gait is impacted by cultural factors. We specifically targeted articles published after 2013 following the change in diagnostic criteria of autism spectrum disorder. A review of 43 recently published articles revealed that culture has not been considered in autism gait studies. It is clear from this review that studies assessing gait in ASD must consider the impact of cultural factors.

With the increasing prevalence of autism globally, neuroscientific research exploring the underlying neurobiological differences in the development of autistic characteristics, such as gross motor skills, is crucial to better understand, diagnose and serve autistic individuals. Although a body of scientific literature has indicated that the study of gait in autistic walkers may objectively quantify gross motor differences and could potentially lead to methods of earlier diagnosis, it is urgent for these studies to report the participants' cultural background such as race, ethnicity, socioeconomic status, country of origin, and cultural identity to ensure that the results can be generalized across all autistic individuals. In fact, there was a complete lack of information regarding participant characteristics in the 43 articles that were reviewed for the present scoping review.

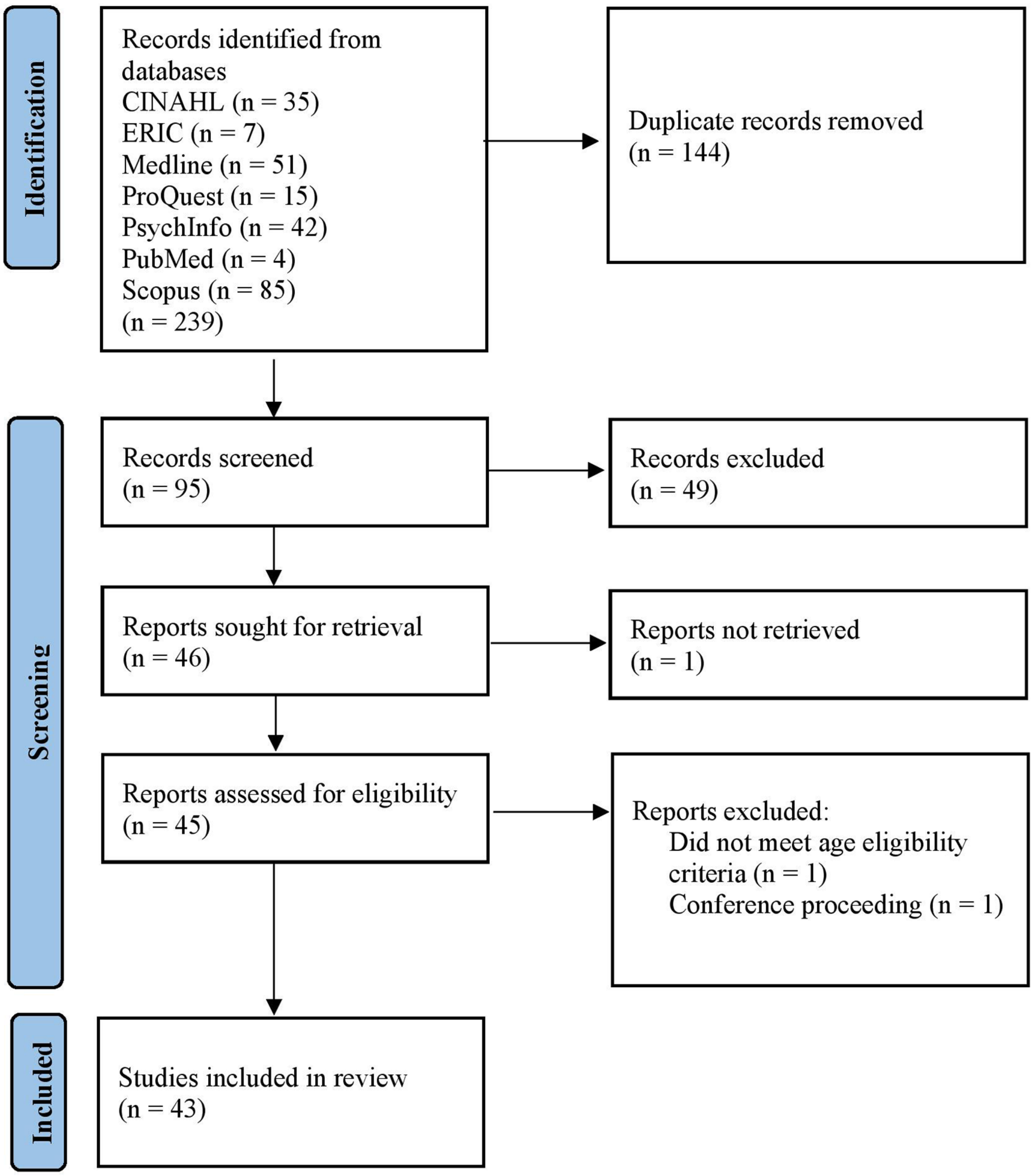

Fig. 1. Article Selection Process. PRISMA 2020 flow diagram describing the article selection process.

Most studies only reported age and sex information. We would further like to propose the need for more information to be included in future publications regarding autism diagnostic criteria. Many studies included in the present review did not report how the participants obtained the ASD diagnosis. This lack of information paired with the fact that most gait studies have been conducted with White and Western individuals, could lead to misinterpretations of the findings, and could delay the advancement of scientifically sound diagnostic tools and services to autistic individuals.

Given the potential promise of using walking gait to further our understanding of ASD and its neural underpinnings, we would like to propose that future studies take culture into consideration. We outline several ways in which culture can be incorporated into future studies. First, the inclusion of autistic researchers across a variety of backgrou-

Table 1. Summary of included studies (*n* = 43).

Author(s)	Total participants; ASD participants, ASD participants assigned male at birth	Age range of ASD participants	ASD Diagnostic Criteria	Culture considered?
Accardo and Barrow, 2015 [32]	*n* = 61; ASD = 61, male = 54	19–36 mos.	DSM-IV	No
Arik, Aksoy, Aysev and Akçakin, 2018 [33]	*n* = 79; ASD = 79, male = 66	2–16 yrs.	DSM-IV	No
Armitano-Lago, Bennett and Haegele, 2021 [34]	*n* = 34; ASD = 17, male = 12	13.5–16.5 yrs.	DSM-IV DSM-5	No
Bennett and Haegele, 2021 [35]	*n* = 34; ASD = 17, male = 12	13.2–16.2 yrs.	Documentation confirming diagnosis	No
Bennett, Ringleb, Bobzien and Haegele, 2022 [36]	*n* = 34; ASD = 17, male = 12	13.2–16.2 yrs.	Documentation confirming diagnosis	No
Bennett, Ringleb, Bobzien and Haegele, 2021 [37]	*n* = 34; ASD = 17, male = 12	13.2–16.2 yrs.	Documentation confirming diagnosis	No
Bennett, Jones, Valenzuela and Haegele, 2021 [38]	*n* = 20; ASD = 10, male = 10	13.2–16.2 yrs.	Documentation confirming diagnosis	No
Biffi *et al*., 2018 [39]	*n* = 31; ASD = 15, male = 14	8.24–11.38 yrs.	DSM-5 Confirmed with ADOS	No
Eggleston *et al*., 2020 [40]	*n* = 21; ASD = 11, male = N/A	5–12 yrs.	DSM-IV DSM-5	No
Eggleston *et al*., 2018 [41]	*n* = 10; ASD =10, male = 10	7.2–15 yrs.	Verbally confirmed by parent	No
Eggleston *et al*., 2018 [42]	*n* = 8; ASD = 8, male = 8	7.1–16.1 yrs.	Parent-confirmed diagnosis from a psychiatrist or psychologist	No
Eggleston, Harry and Dufek, 2018 [43]	*n* = 18; ASD = 9, male = 7	6.7–11.3 yrs.	Verbally confirmed by parent	No
Eggleston, Harry, Hickman and Dufek, 2017 [44]	*n* = 10; ASD = 10, male = 6	5–12 yrs.	Verbally confirmed by parent	No
El Shemy and El-Sayed, 2018 [45]	*n* = 30; ASD = 30, male = 22	8.65–9.99 yrs.	CARS	No
Golden and Getchell, 2017 [46]	*n* = 17; ASD = 9, male = 9	8–11 yrs.	Previous diagnosis from psychologist and/or physician Confirmed with SRS-2	No
Gong *et al*., 2020 [47]	*n* = 86; ASD = 58, male = 52	4.21–6.86 yrs.	DSM-5 Confirmed with AQ-CHILD and SRS-2	No
Gürol, 2019 [48]	*n* = 21; ASD = 21, male = 21	9.41–13.73 yrs.	None specified	No
Hasan, Jailani and Tahir, 2017 [49]	*n* = 60; ASD = 30, male = 23	6.47–10.79 yrs.	None specified	No
Hasan, Jailani, Tahir and Desa, 2018 [50]	*n* = 60; ASD = 30, male = 23	6.47–10.79 yrs.	Clinically diagnosed, none specified	No
Hasan, Jailani, Tahir and Ilias, 2017 [51]	*n* = 35; ASD = 15, male = 11	7.61–11.73 yrs.	Previous diagnosis	No
Hasan, Jailani, Tahir and Sahak, 2017 [52]	*n* = 60; ASD = 30, male = N/A	4–12 yrs.	None specified	No
Jafarnezhadgero *et al*., 2021 [53]	*n* = 30; ASD = 15, male = 15	8.3–9.7 yrs.	Parent or teacher report	No
Li, Koldenhoven, Liu and Venuti, 2021 [54]	*n* = 29; ASD = 29, male = N/A	6–14 yrs.	DSM-5	No

Table 1. Continued.

Author(s)	Total participants; ASD participants, ASD participants assigned male at birth	Age range of ASD participants	ASD Diagnostic Criteria	Culture considered?
Lim, O'Sullivan, Choi and Kim, 2016 [55]	*n* = 30; ASD =15, male = 13	8.4–14 yrs.	DSM- IV	No
Manfredi, Riefoli, Coviello and Dibello, 2022 [56]	*n* = 22; ASD = 22, male = 12	5.6–12.6 yrs.	DSM-5	No
Manicolo *et al*., 2019 [57]	*n* = 68; ASD = 32, male = 27	5.2–12.8yrs	ICD-10	No
Mason, Padilla and Travers, 2022 [58]	*n* = 27; ASD = 9, male = 8	11–12.4 yrs.	Previous clinical diagnosis Confirmed with ADOS-2	No
Mohd Nor, Jailani and Tahir, 2020 [59]	*n* = 60; ASD = 30, male = N/A	6–13 yrs.	None specified	No
Mohd Nor *et al*., 2016 [60]	*n* = 18; ASD = 8, male = N/A	6–13yrs.	None specified	No
Olivas, Chavez and Eggleston, 2022 [61]	*n* = 9; ASD = 9, male = 8	9.6–15.8 yrs.	Clinical diagnosis verbally confirmed by parent	No
Olivas *et al*., 2022 [62]	*n* = 14; ASD = 14, male = 12	8–17 yrs.	Documentation from medical professionals or school IEP	No
Pauk, Zawadska, Wasilewska and Godlewski, 2017 [63]	*n* = 58; ASD = 28, male = 17	5.1–9.8 yrs.	CARS	No
Pradhan, Chester and Padhiar, 2022 [64]	*n* = 40; ASD = 19, male = 16	7.6–13.4 yrs.	None specified	No
Sengupta *et al*., 2021 [65]	*n* = 1; ASD =1, male = N/A	10 yrs.	None specified	No
Shetreat-Klein, Shinnar and Rapin, 2014 [66]	*n* = 76; ASD = 38, male = 28	1.83–10.76 yrs.	DSM-IV	No
Souza *et al*., 2020 [67]	*n* = 6; ASD = 6, male = 2	3–17 yrs.	CARS	No
Steiner and Kertesz, 2015 [68]	*n* = 26; ASD = 26, male = 12	10–13 yrs.	None specified	No
Telang, Naqvi, Dhankar and Jungade, 2021 [69]	*n* = 20; ASD =20, male = N/A	4–10 yrs.	None specified	No
Valagussa *et al*., 2020 [70]	*n* = 69; ASD = 69, male = 56	14.1 (±3.6 yrs.)	DSM-5 Confirmed with ADOS-2	No
Wilder *et al*., 2020 [71]	*n* = 3; ASD =3, male = 3	4–6 yrs.	None specified	No
Wilson *et al.,* 2020 [72]	*n* = 191; ASD = 21, male = 71%	30 mos.–11 yrs.	ADOS-2	No
Zakaria, Jailani and Tahir, 2021 [73]	*n* = 53; ASD = 23, male = 21	8–8.8 yrs.	None specified	No
Zakaria *et al*., 2017 [74]	*n* = 40; ASD = 10, male = N/A	8.40 (1.90) yrs.	Previous clinical diagnosis	No

Note. ASD, Autism spectrum disorder; m, Male; N/A, Not available; mos., Months; yrs., Years; DSM, Diagnostic and Statistical Manual of Mental Disorders; ADOS, Autism Diagnostic Observation Schedule; CARS, Childhood Autism Rating Scale; SRS, Social Responsiveness Scale; AQ-Child, Autism Spectrum Quotient: Children's Version; ICD, International Classification of Diseases; IEP, Individualized Education Program.

nds as collaborators on research teams could help identify potential areas of research bias as the study methods are in the development stage and in the interpretation of the results. This community-based participatory research approach is gaining momentum in health-based research, with the ultimate goal of improving the science of addressing health disparities in socially disadvantaged population groups [75–78]. Second, active recruitment of autistic participants across a broad range of cultural, racial, and socioeconomic backgrounds could also help to disentangle which aspects of gait are unique to ASD irrespective of cultural, racial, or socioeconomic status. Cultural factors do impact every aspect of ASD, from the referral and diagnostic process to the way that the child is accepted and integrated into the overall society [79]. Perhaps autistic children with more involved needs, such as intellectual needs, may be approached differently within different cultures, which could have further implications for how they in turn adopt cultural norms, such as walking gait. In fact, a relationship between intellectual functioning and motor skills has been documented, such that individuals with lower intellectual functioning often demonstrate poorer motor performance [80–82] and given that autism is a spectrum disorder, some autistic children also have an intellectual disability. In fact, one-third of autistic children also have intellectual disability [83]. Third, a way to help increase the diversity of participants is to ensure that researchers undertaking these studies come from a variety of backgrounds and experiences and that all researchers undergo cultural humility training. This would allow the researchers to establish trusting relationships with all participants from all backgrounds. Ultimately, for neuroscientific researchers to more accurately study gait in autistic individuals, cultural factors must be taken into consideration in future research.

The present scoping review is not without limitations. We considered culture very broadly, but even with this broad definition of culture, none of the 43 articles took culture into account. Further, there are sex differences in the biomechanics of gait [23] but we did not specifically assess whether these studies took these sex differences into account. Gaging by the number of ASD participants assigned male at birth, as illustrated in Table 1, it appears that the current research assessing the relationship between autism and the biomechanics of gait is male dominated. Historically, the ratio of male to females diagnosed with ASD has been reported to be 4 males to 1 female [84]; however, it has become increasingly evident that autistic characteristics differ between males and females and this ratio is in fact much lower [85]. Future work is necessary to consider sex differences in addition to cultural factors.

5. Conclusions

Motor differences in autistic children have been widely reported [3,4,86], and may point to an early diagnostic indicator of ASD [5]. In particular, poor postural control, necessary to maintain upright balance, in infants as young as 6 months of age is one of the earliest identified indicators of ASD [7]. As toddlers continue to grow and learn to walk, gait differences have also been observed in autistic children. Thus, gait differences may serve clinical utility and as an early indicator of ASD. In order to provide culturally responsive assessment and intervention services, studies assessing gait in autistic children should consider the impact of culture on gait. An urgent call to action is necessary to ensure that children from all cultural backgrounds are recruited for research studies, and that investigators consider culture in the study design, recruitment, and data analysis process. This is the first step to creating equitable ASD screening, diagnostic, and intervention tools.

Availability of Data and Materials

The dataset is available from the corresponding author on reasonable request.

Author Contributions

MB, AG, SO and ZW designed the research study. Under the supervision of MB, GI and RT performed the research and analyzed the data. MB, AG, and SO wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Appendix

One of the seven researched database searched for the present scoping review included the ERIC EBSCO host. The following steps were taken to obtain relevant articles:

Table 2. Example of full electronic search strategy.

Step 1	Type the keywords in the advanced search tab "Autism or ASD or autism spectrum disorder or autis" and "gait or walking".
Step 2	Click both tabs selecting "title" in the select field, then press "search".
Step 3	Repeat the previous step but instead of selecting "title" for the select field, select "abstract" then press "search".
Step 4	Following both searches, press on "search history", click on "select/deselect all" and press "search with AND".
Step 5	Scroll down to "source types" and press on "academic journals".
Step 6	Once the page updates, click on the folder icon on the top right corner of the article if it is relevant to the research question.
Step 7	Once all articles that are relevant are selected into a folder, press "folder view".
Step 8	Press "select/deselect all" then press "export".
Step 9	Once exported, go under "save citations to a file formatted for:" and press "download CSV".
Step 10	Press save. This will then allow us to retrieve all information regarding an article into an excel spreadsheet.

References

[1] World Health Organization. Autism. 2022. Available at: https://www.who.int/news-room/fact-sheets/detail/autism-spectrum-disorders (Accessed: 3 December 2022).

[2] American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders. 5th edn. American Psychiatric Association: Arlington, VA, USA. 2022.

[3] Green D, Charman T, Pickles A, Chandler S, Loucas T, Simonoff E, *et al*. Impairment in movement skills of children with autistic spectrum disorders. Developmental Medicine and Child Neurology. 2009; 51: 311–316.

[4] Odeh CE, Gladfelter AL, Stoesser C, Roth S. Comprehensive motor skills assessment in children with autism spectrum disorder yields global deficits. International Journal of Developmental Disabilities. 2020; 68: 290–300.

[5] May T, McGinley J, Murphy A, Hinkley T, Papadopoulos N, Williams K J, *et al*. A multidisciplinary perspective on motor impairment as an early behavioral marker in children with autism spectrum disorder. Australian Psychologist. 2016; 51: 296–303.

[6] Downey R, Rapport MJK. Motor activity in children with autism: a review of current literature. Pediatric Physical Therapy: the Official Publication of the Section on Pediatrics of the American Physical Therapy Association. 2012; 24: 2–20.

[7] Flanagan JE, Landa R, Bhat A, Bauman M. Head lag in infants at risk for autism: a preliminary study. The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association. 2012; 66: 577–585.

[8] Ozonoff S, Young GS, Goldring S, Greiss-Hess L, Herrera AM, Steele J, *et al*. Gross motor development, movement abnormalities, and early identification of autism. Journal of Autism and Developmental Disorders. 2008; 38: 644–656.

[9] Ament K, Mejia A, Buhlman R, Erklin S, Caffo B, Mostofsky S, *et al*. Evidence for specificity of motor impairments in catching and balance in children with autism. Journal of Autism and Developmental Disorders. 2015; 45: 742–751.

[10] Memari AH, Ghanouni P, Shayestehfar M, Ghaheri B. Postural control impairments in individuals with autism spectrum disorder: a critical review of current literature. Asian Journal of Sports Medicine. 2014; 5: e22963.

[11] Perin C, Valagussa G, Mazzucchelli M, Gariboldi V, Cerri CG, Meroni R, *et al*. Physiological Profile Assessment of Posture in Children and Adolescents with Autism Spectrum Disorder and Typically Developing Peers. Brain Sciences. 2020; 10: 681.

[12] Kloos AD, Givens DL. Exercise for impaired balance. In Duffield, M.A (ed.) Therapeutic exercise: Foundations and techniques. 7th edn. F.A. Davis Company: Philadelphia. 2018.

[13] Yimgang DP, Albury RA, Leppert ML. Do Parental Concerns Predict Developmental and Behavioral Diagnoses in a Developmental Clinic? Clinical Pediatrics. 2017; 56: 263–267.

[14] Guinchat V, Chamak B, Bonniau B, Bodeau N, Perisse D, Cohen D, *et al*. Very early signs of autism reported by parents include many concerns not specific to autism criteria. Research in Autism Spectrum Disorders. 2012; 6: 589–601.

[15] Vilensky JA, Damasio AR, Maurer RG. Gait disturbances in patients with autistic behavior: a preliminary study. Archives of Neurology. 1981; 38: 646–649.

[16] Nayate A, Tonge BJ, Bradshaw JL, McGinley JL, Iansek R, Rinehart NJ. Differentiation of high-functioning autism and Asperger's disorder based on neuromotor behaviour. Journal of Autism and Developmental Disorders. 2012; 42: 707–717.

[17] Calhoun M, Longworth M, Chester VL. Gait patterns in children with autism. Clinical Biomechanics (Bristol, Avon). 2011; 26: 200–206.

[18] Weiss MJ, Moran MF, Parker ME, Foley JT. Gait analysis of teenagers and young adults diagnosed with autism and severe verbal communication disorders. Frontiers in Integrative Neuroscience. 2013; 7: 33.

[19] Rinehart NJ, Tonge BJ, Bradshaw JL, Iansek R, Enticott PG, McGinley J. Gait function in high-functioning autism and Asperger's disorder: evidence for basal-ganglia and cerebellar involvement? European Child & Adolescent Psychiatry. 2006; 15: 256–264.

[20] Chester VL, Calhoun M. Gait symmetry in children with autism. Autism Research and Treatment. 2012; 2012: 576478.

[21] Whyatt CP, Craig CM. Motor skills in children aged 7–10 years, diagnosed with autism spectrum disorder. Journal of Autism and Developmental Disorders. 2012; 42: 1799–1809.

[22] Nobile M, Perego P, Piccinini L, Mani E, Rossi A, Bellina M, *et al*. Further evidence of complex motor dysfunction in drug naive children with autism using automatic motion analysis of gait. Autism: the International Journal of Research and Practice. 2011; 15: 263–283.

[23] Ambrosini D, Courchesne E, Kaufman K. Motion analysis of patients with infantile autism. Gait & Posture. 1998; 7: 188.

[24] Cho SH, Park JM, Kwon OY. Gender differences in three dimensional gait analysis data from 98 healthy Korean adults. Clinical Biomechanics (Bristol, Avon). 2004; 19: 145–152.

[25] Ebersbach G, Sojer M, Müller J, Heijmenberg M, Poewe W. Sociocultural differences in gait. Movement Disorders: Official Journal of the Movement Disorder Society. 2000; 15: 1145–1147.

[26] Karasik LB, Adolph KE, Tamis-Lemonda CS, Bornstein MH. WEIRD walking: cross-cultural research on motor development. The Behavioral and Brain Sciences. 2010; 33: 95–96.

[27] Ryu T, Choi HS, Choi H, Chung MK. A comparison of gait characteristics between Korean and Western people for establishing Korean gait reference data. International Journal of Industrial Ergonomics. 2006; 36: 1023–1030.

[28] Rasmussen HN, Lavish L. Broad definitions of culture in the field of multicultural psychology. In Pedrotti, J.T. & Edwards, L. (eds.) Perspectives on the Intersection of Positive Psychology

and Multiculturalism (pp. 17–30). Springer: Dordrecht. 2014.
[29] Al-Obaidi S, Wall JC, Al-Yaqoub A, Al-Ghanim M. Basic gait parameters: a comparison of reference data for normal subjects 20 to 29 years of age from Kuwait and Scandinavia. Journal of Rehabilitation Research and Development. 2003; 40: 361–366.
[30] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. International Journal of Social Research Methodology. 2005; 8: 19–32.
[31] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic Reviews. 2021; 10: 89.
[32] Accardo PJ, Barrow W. Toe walking in autism: further observations. Journal of Child Neurology. 2015; 30: 606–609.
[33] Arik A, Aksoy C, Aysev A, Akçakin M. Lower-extremity rotational profile and toe-walking in preschool children with autism spectrum disorder. Journal of Pediatric Orthopedics. Part B. 2018; 27: 530–534.
[34] Armitano-Lago C, Bennett HJ, Haegele JA. Lower Limb Proprioception and Strength Differences Between Adolescents With Autism Spectrum Disorder and Neurotypical Controls. Perceptual and Motor Skills. 2021; 128: 2132–2147.
[35] Bennett HJ, Haegele JA. Running Biomechanics of Adolescents With Autism Spectrum Disorder. Journal of Biomechanical Engineering. 2021; 143: 111005.
[36] Bennett HJ, Ringleb SI, Bobzien J, Haegele JA. Are Gait Biomechanics Related to Physical Activity Engagement? An Examination of Adolescents with Autism Spectrum Disorder. Medicine and Science in Sports and Exercise. 2022; 54: 447–455.
[37] Bennett HJ, Ringleb SI, Bobzien J, Haegele JA. Walking lower extremity biomechanics of adolescents with autism spectrum disorder. Journal of Biomechanics. 2021; 119: 110332.
[38] Bennett HJ, Jones T, Valenzuela KA, Haegele JA. Inter and intra-limb coordination variability during walking in adolescents with autism spectrum disorder. Clinical Biomechanics (Bristol, Avon). 2021; 89: 105474.
[39] Biffi E, Costantini C, Ceccarelli SB, Cesareo A, Marzocchi GM, Nobile M, *et al*. Gait Pattern and Motor Performance During Discrete Gait Perturbation in Children With Autism Spectrum Disorders. Frontiers in Psychology. 2018; 9: 2530.
[40] Eggleston JD, Harry JR, Cereceres PA, Olivas AN, Chavez EA, Boyle JB, *et al*. Lesser magnitudes of lower extremity variability during terminal swing characterizes walking patterns in children with autism. Clinical Biomechanics (Bristol, Avon). 2020; 76: 105031.
[41] Eggleston JD, Landers MR, Bates BT, Nagelhout E, Dufek JS. Weighted Walking Influences Lower Extremity Coordination in Children on the Autism Spectrum. Perceptual and Motor Skills. 2018; 125: 1103–1122.
[42] Eggleston JD, Landers MR, Bates BT, Nagelhout E, Dufek JS. Examination of gait parameters during perturbed over-ground walking in children with autism spectrum disorder. Research in Developmental Disabilities. 2018; 74: 50–56.
[43] Eggleston JD, Harry JR, Dufek JS. Lower extremity joint stiffness during walking distinguishes children with and without autism. Human Movement Science. 2018; 62: 25–33.
[44] Eggleston JD, Harry JR, Hickman RA, Dufek JS. Analysis of gait symmetry during over-ground walking in children with autism spectrum disorder. Gait & Posture. 2017; 55: 162–166.
[45] El Shemy SA, El-Sayed MS. The impact of auditory rhythmic cueing on gross motor skills in children with autism. Journal of Physical Therapy Science. 2018; 30: 1063–1068.
[46] Golden D, Getchell N. Physical Activity Levels in Children With and Without Autism Spectrum Disorder When Playing Active and Sedentary Xbox Kinect Videogames. Games for Health Journal. 2017; 6: 97–103.
[47] Gong L, Liu Y, Yi L, Fang J, Yang Y, Wei K. Abnormal Gait Patterns in Autism Spectrum Disorder and Their Correlations with Social Impairments. Autism Research: Official Journal of the International Society for Autism Research. 2020; 13: 1215–1226.
[48] Gürol B. Analysis of Gait Patterns in Individuals with Autism Spectrum Disorder After Recreational Therapy Program at Eskisehir Technical University. International Education Studies. 2019; 12: 105–110.
[49] Hasan CZC, Jailani R, Tahir NM. Use of statistical approaches and artificial neural networks to identify gait deviations in children with autism spectrum disorder. International Journal of Biology and Biomedical Engineering. 2017; 11: 74–79.
[50] Hasan CZC, Jailani R, Tahir NM, Desaa HM. Vertical ground reaction force gait patterns during walking in children with autism spectrum disorders. International Journal of Engineering, Transactions B: Applications. 2018; 31: 705–711.
[51] Hasan CZC, Jailani R, Md Tahir N, Ilias S. The analysis of three-dimensional ground reaction forces during gait in children with autism spectrum disorders. Research in Developmental Disabilities. 2017; 66: 55–63.
[52] Hasan CZC, Jailani R, Tahir NM, Sahak R. Autism spectrum disorders gait identification using ground reaction forces. Telkomnika (Telecommunication Computing Electronics and Control). 2017; 15: 903–911.
[53] Jafarnezhadgero AA, Dehghani M, Abdollahpourdarvishani M, Sheikhalizadeh H, Akrami M. Effect of textured foot orthoses on walking plantar pressure variables in children with autism spectrum disorders. Journal of Biomechanics. 2021; 129: 110775.
[54] Li Y, Koldenhoven RM, Liu T, Venuti CE. Age-related gait development in children with autism spectrum disorder. Gait & Posture. 2021; 84: 260–266.
[55] Lim B, O'Sullivan D, Choi B, Kim M. Comparative gait analysis between children with autism and age-matched controls: analysis with temporal-spatial and foot pressure variables. Journal of Physical Therapy Science. 2016; 28: 286–292.
[56] Manfredi F, Riefoli F, Coviello M, Dibello D. The Management of Toe Walking in Children with Autism Spectrum Disorder: *"Cast and Go"*. Children (Basel, Switzerland). 2022; 9: 1477.
[57] Manicolo O, Brotzmann M, Hagmann-von Arx P, Grob A, Weber P. Gait in children with infantile/atypical autism: Age-dependent decrease in gait variability and associations with motor skills. European Journal of Paediatric Neurology: EJPN: Official Journal of the European Paediatric Neurology Society. 2019; 23: 117–125.
[58] Mason AH, Pickett KA, Padilla AS, Travers BG. Combined Gait and Grasping in Autistic and Non-Autistic Youths. Developmental Neurorehabilitation. 2022; 25: 452–461.
[59] Mohd Nor MN, Jailani R, Tahir NM. Feature selection of electromyography signals for autism spectrum disorder children during gait using mann-whitney test. Jurnal Teknologi. 2020; 82: 113–120.
[60] Mohd Nor MN, Jailani R, Tahir NM, Ismael Rizman Z, Mohd Yassin I, Hidayat R. EMG Signals Analysis of BF and RF Muscles In Autism Spectrum Disorder (ASD) During Walking. International Journal on Advanced Science, Engineering and Information Technology. 2016; 6: 793–798.
[61] Olivas AN, Chavez EA, Eggleston JD. Weighted Vest Loads Do Not Elicit Changes in Spatial-Temporal Gait Parameters in Children and Adolescents With Autism. Journal of Applied Biomechanics. 2022; 38: 391–397.
[62] Olivas AN, Kendall MR, Parada A, Manning R, Eggleston JD. Children with autism display altered ankle strategies when changing speed during over-ground gait. Clinical Biomechanics (Bristol, Avon). 2022; 100: 105804.
[63] Pauk J, Zawadzka N, Wasilewska A, Godlewski P. Gait devia-

tions in children with classic high-functioning autism and low-functioning autism. Journal of Mechanics in Medicine and Biology. 2017; 17: 1750042.
[64] Pradhan A, Chester V, Padhiar K. Classification of Autism and Control Gait in Children Using Multisegment Foot Kinematic Features. Bioengineering (Basel, Switzerland). 2022; 9: 552.
[65] Sengupta T, Devaraj A, Karthik V, Altaf H, Gupta M. Trace-tracking relational axes and comparative evaluation. Biomedical Engineering: Applications, Basis and Communications. 2021; 33: 2150008.
[66] Shetreat-Klein M, Shinnar S, Rapin I. Abnormalities of joint mobility and gait in children with autism spectrum disorders. Brain & Development. 2014; 36: 91–96.
[67] de Souza FHN, Lisboa AKP, Maia MDFT, Dos Santos MRD, da Silva Filho EM, Cezarino LG, *et al*. Effects of dual task training on gait temporal-spatial parameters of children with autism. Manual Therapy, Posturology & Rehabilitation Journal. 2017; 1–5.
[68] Steiner H, Kertesz Z. Effects of therapeutic horse riding on gait cycle parameters and some aspects of behavior of children with autism. Acta Physiologica Hungarica. 2015; 102: 324–335.
[69] Telang P, Naqvi W, Dhankar S, Jungade S. Effect of Manual Therapy (MET) versus conventional therapy for improving tendo-achilles flexibility and foot posture in children with autism spectrum disorder. Journal of Datta Meghe Institute of Medical Sciences University. 2021; 16: 505.
[70] Valagussa G, Balatti V, Trentin L, Piscitelli D, Yamagata M, Grossi E. Relationship between tip-toe behavior and soleus - gastrocnemius muscle lengths in individuals with autism spectrum disorders. Journal of Orthopaedics. 2020; 21: 444–448.
[71] Wilder DA, Ertel H, Hodges AC, Thomas R, Luong N. The use of auditory feedback and edible reinforcement to decrease toe walking among children with autism. Journal of Applied Behavior Analysis. 2020; 53: 554–562.
[72] Wilson RB, Elashoff D, Gouelle A, Smith BA, Wilson AM, Dickinson A, *et al*. Quantitative Gait Analysis in Duplication 15q Syndrome and Nonsyndromic ASD. Autism Research: Official Journal of the International Society for Autism Research. 2020; 13: 1102–1110.
[73] Zakaria NK, Jailani R, Alam S, Nooritawati M, Tahir M. A Markerless-Based Gait Analysis and Visualization Approach for ASD Children. International Journal of Advanced Computer Science and Applications. 2021; 12.
[74] Zakaria NK, Syaiful L, Mustafah NM, Manaf H, Ismail M, Jamil N. Can gait deviation index (GDI) be an early indicator for children with autistic spectrum disorder (ASD)? International Information Institute (Tokyo), Information, Koganei. 2017; 20: 6351–6360.
[75] Holkup PA, Tripp-Reimer T, Salois EM, Weinert C. Community-based participatory research: an approach to intervention research with a Native American community. ANS. Advances in Nursing Science. 2004; 27: 162–175.
[76] Shalowitz MU, Isacco A, Barquin N, Clark-Kauffman E, Delger P, Nelson D, *et al*. Community-based participatory research: a review of the literature with strategies for community engagement. Journal of Developmental and Behavioral Pediatrics: JDBP. 2009; 30: 350–361.
[77] Cyril S, Smith BJ, Possamai-Inesedy A, Renzaho AMN. Exploring the role of community engagement in improving the health of disadvantaged populations: a systematic review. Global Health Action. 2015; 8: 29842.
[78] Community-Based Participatory Research Program (CBPR). National Institutes on Minority health and Health and Health Disparities. 2018. Available at: https://www.nimhd.nih.gov/programs/extramural/community-based-participatory.html (Accessed: 19 December 2022).
[79] Bernier R, Mao A, Yen J. Psychopathology, families, and culture: autism. Child and Adolescent Psychiatric Clinics of North America. 2010; 19: 855–867.
[80] Hartman E, Houwen S, Scherder E, Visscher C. On the relationship between motor performance and executive functioning in children with intellectual disabilities. Journal of Intellectual Disability Research: JIDR. 2010; 54: 468–477.
[81] Smits-Engelsman B, Hill EL. The relationship between motor coordination and intelligence across the IQ range. Pediatrics. 2012; 130: e950–6.
[82] Westendorp M, Houwen S, Hartman E, Visscher C. Are gross motor skills and sports participation related in children with intellectual disabilities? Research in Developmental Disabilities. 2011; 32: 1147–1153.
[83] Centers for Disease Control and Prevention. Autism and Developmental Disabilities Monitoring (ADDM) Network. 2022. Available at: https://www.cdc.gov/ncbddd/autism/addm.html#:~:text=Among%20children%20identified%20with%20ASD,%25)%20also%20had%20intellectual%20disability (Accessed: 9 January 2023).
[84] Centers for Disease Control and Prevention. What is Autism Spectrum Disorder? 2022. Available at: https://www.cdc.gov/ncbddd/autism/facts.html (Accessed: 20 December 2022).
[85] D'Mello AM, Frosch IR, Li CE, Cardinaux AL, Gabrieli JDE. Exclusion of females in autism research: Empirical evidence for a "leaky" recruitment-to-research pipeline. Autism Research: Official Journal of the International Society for Autism Research. 2022; 15: 1929–1940.
[86] Gladfelter A, Johnson E, Odeh CE. Parent perceptions of social behaviors associated with autism spectrum disorder are related to motor skills. Communication Disorders Quarterly. 2020; 41: 193–194.