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The Association Between Motor and Social Skills in Young Autistic Children Enrolled in the Study to Explore Early Development

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Abstract

Motor difficulties are common in autistic individuals and may contribute to challenges in social development. Understanding the association between motor and social skills could inform interventions to improve developmental outcomes. Using data from the Study to Explore Early Development—a large, diverse sample of rigorously characterized preschool-aged autistic children in the United States—we aimed to (a) describe the frequency of motor challenges using multiple standardized instruments; and (b) evaluate associations between motor and social skills. Children were identified from health and education organizations and birth records. Caregivers completed standardized interviews and questionnaires, and children completed comprehensive developmental evaluations to determine autism status. Among 2,039 children meeting the study autism criteria, 67.3% exhibited motor scores ⩾2 standard deviations below the mean on at least one measure. Motor difficulties were more prevalent in the fine motor (up to 63.4%) than gross motor (14.2%) domain and among children with significant visual reception delays (up to 92.8%) than those without these delays (up to 32.0%). After adjusting for covariates, fine motor skills were significantly associated with social challenges in both functional and autism-specific domains. These findings highlight the importance of motor development in early autism evaluations.

Lay abstract

Many autistic children have challenges with movement skills, such as crawling, walking, or using their hands for tasks like drawing or eating. These motor difficulties can also affect how children learn, play, and interact with others. Understanding how motor and social skills are connected may help improve early support for autistic children. This study used data from the Study to Explore Early Development, a large research project that included preschool-aged autistic children from diverse communities across the United States. Parents completed interviews and surveys about their child's development, and each child was evaluated by trained professionals to better understand their strengths and needs. We looked at over 2,000 autistic children and found that about 67% (two out of three) had motor skill scores that were well below what's typical for their age. Motor difficulties were more common when children used small muscles in the hands and fingers, like when drawing or eating, than when they used large muscles, like when crawling or walking. We also found that children with stronger motor skills tended to have fewer social challenges. These results show that motor delays are not only common in young autistic children but may also be linked to how they develop social skills. Spotting motor difficulties early could help families and professionals better support each child's development. Supporting motor skills in early childhood, along with communication and behavior, might help autistic

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children build stronger social connections. By raising awareness about the role of motor skills in autism, we could help make interventions more effective and equitable, leading to autistic children learning, playing, and connecting with others more easily.

Keywords
autism spectrum disorder, child, epidemiology, motor skills, preschool, social behavior

Introduction

Motor skill challenges are common in autistic individuals, with an estimated prevalence between 50% and 88% (Kangarani-Farahani et al., 2024; Pokoski et al., 2025; Wang et al., 2022). These challenges are heterogeneous and can present in a variety of ways including motor milestone delays (Reynolds et al., 2022), fine or gross motor impairments (Lloyd et al., 2013), poor coordination (Fournier et al., 2010), reduced grip strength (Travers et al., 2017), and postural instability (Memari et al., 2014; Travers et al., 2013). While the elevated frequency of motor difficulties in autistic individuals has been noted since the earliest clinical descriptions (Kanner, 1943; Wing, 1997), motor skills in autism have received growing attention in recent years, partially due to their potential use in autism evaluation and diagnosis (Pokoski et al., 2025). However, because motor impairments are not currently included in autism diagnostic definitions and are neither specific to autism nor universal in individuals diagnosed with autism, their identification may depend on the priorities of individual clinicians or standard protocols (Bhat, 2021; Licari et al., 2020). This variability can lead to missed or delayed referrals for early interventions or physical therapies to support motor skill development, especially when motor difficulties are overshadowed by social or behavioral concerns.

Several studies have highlighted the interconnected nature of motor and social skills in autism (Craig et al., 2021; Mandelli et al., 2024). Motor skill development in infancy plays a foundational role in fostering engagement with objects and individuals, allowing for increased social interactions, and potentially influencing broader developmental milestones (Bhat, 2021; Iverson et al., 2019; Ohara et al., 2019; Posar & Visconti, 2022). Delays in motor development can compound over time, exacerbating social difficulties and limiting participation in meaningful activities; this limited participation may in turn reduce opportunities for acquisition and practice of both motor and social skills (Holloway & Long, 2019; Lim et al., 2021; Lloyd et al., 2013; MacDonald et al., 2013; Teh et al., 2024; West, 2019). Evidence indicates that race and cultural context may shape how parents perceive and communicate developmental concerns during the autism diagnostic process, which may influence how early motor and social challenges are recognized and documented (Azad et al., 2022). These differences highlight the importance of considering race when examining heterogeneity in motor and social development in autistic children. Attention to the links between motor and social development can inform how we interpret differences in neurodevelopmental trajectories among autistic children. However, most studies examining this relationship in autistic individuals were based on small, clinical samples. A systematic review by Ohara et al. (2019) found that 12 of 16 studies reported significant positive associations between motor and social skills. Despite the relative consistency of these results, these studies varied widely in measurement, methods, and included participants across broad age ranges, limiting the ability to conduct a meta-analysis. These limitations highlight the need for larger samples using multiple standardized assessments of both motor and social skills to better understand their relationship in autism. Evaluating motor and social skills across multiple instruments allows for identification of both convergent and divergent patterns across commonly used measures, which may inform interpretation of findings. Using multiple instruments also reduces reliance on any single measure and facilitates interpretation across tools commonly used in autism research and clinical practice. The present study addresses these gaps by utilizing a large, diverse, community-based sample of rigorously characterized preschool-aged autistic children and incorporating multiple validated instruments to comprehensively assess motor and social skills through two main objectives: (a) to describe motor and social skills in the study sample using multiple instruments and evaluating similarities and differences in descriptions of motor and social abilities between instruments; and (b) to evaluate associations between motor and social skills in early childhood. We hypothesize that children with better motor skills will exhibit better social skills, a finding that would suggest the importance of understanding motor development in the context of broader social functioning.

Methods

Study Sample

The Study to Explore Early Development (SEED) is a multisite case-control study that began in 2007 with the goals of identifying risk factors for autism and characterizing autism behavioral phenotypes and associated developmental, medical, and behavioral conditions (Schendel et al., 2012). Children were identified through sources that served or evaluated children with developmental disabilities including early intervention programs, special education services, healthcare providers, and related service programs. In addition, children initially identified as part of the population comparison group through birth certificate review could subsequently be classified as having autism based on screening and diagnostic assessments. Inclusion criteria for SEED participants were as follows: (a) born in 2003–2006 (Phase 1), 2008–2011 (Phase 2), or 2014–2017 (Phase 3); (b) aged 30–68 months at the time of study participation; (c) born and residing in one of the multi-county catchment areas at any of the eight sites in the United States (California, Colorado, Georgia, Maryland, Missouri, North Carolina, Pennsylvania, or Wisconsin) during the study period; (d) caregiver consented to participation; (e) caregiver lived with child since the child was 6 months old or younger; and (f) caregiver communicated in English (or Spanish in the California or Colorado sites).

During the study eligibility assessment, the Social Communication Questionnaire (SCQ), a screening tool, was administered to the participant's caregiver (Rutter et al., 2003). Children who either had previously received an autism diagnosis from a clinician or received an SCQ score ⩾11 participated in comprehensive developmental evaluations conducted by research-reliable clinicians. Participants included in this study were limited to children who met SEED criteria for autism based on gold standard diagnostic assessments, the Autism Diagnostic Observation Schedule (ADOS and ADOS-2) and the Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994, 1999, 2012). SEED enrollment methods, eligibility criteria, and data collection processes are described in detail elsewhere (Schendel et al., 2012; Wiggins et al., 2015).

SEED protocols were approved by the Center for Disease Control and Prevention's Institutional Review Board (IRB) as well as IRBs at each study site. The datasets generated and/or analyzed during the current study are not publicly available to ensure participant confidentiality. Reporting for this study was based on the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (von Elm et al., 2007). The design and implementation of the SEED study incorporated input from community stakeholders, including autistic self-advocates, family members, and service providers. However, the present analyses did not involve direct participation from the autism community.

Measures of Motor and Social Skills

Table 1 outlines each of the motor and social skill measures used in this analysis. For each instrument, it includes the name of the measure, domain or subdomain, method of delivery, type of score used for analysis, mean, standard deviation, range, and study threshold indicating substantial challenges.

Vineland Adaptive Behavior Scales, Second Edition (Vineland-II) Motor Skills Domain. The Vineland-II is a semi-structured caregiver interview designed to assess adaptive behavior used in practical, everyday contexts across four domains: communication, daily living skills, socialization, and motor skills (Sparrow et al., 2005). The motor skills domain is comprised of two subdomains: fine motor skills, which assesses the use of hands and fingers for object manipulation, and gross motor skills, which assesses the use of arms and legs for movement and coordination. Caregivers rated the frequency of behaviors as "never performs," "sometimes performs," or "usually or often performs."

Mullen Scales of Early Learning (MSEL) Fine Motor Domain. The MSEL was administered by SEED clinicians during in-person clinic visits to evaluate the development of children up to 68 months of age across four of five domains: expressive language, receptive language, visual reception, and fine motor (Mullen, 1995). The fine motor domain assesses skills such as dexterity and object manipulation through tasks of increasing difficulty. While the MSEL also includes an optional gross motor domain for use in children up to 33 months of age, this scale was not administered in SEED and thus not included in this study.

Autism Diagnostic Observation Schedule (ADOS). The ADOS is a semi-structured behavioral assessment tool designed to evaluate social interaction, communication, play, and imaginative use of materials for the diagnosis of autism (Lord et al., 1999, 2012). Calibrated severity scores for overall autism symptoms, social affect, and restricted and repetitive behaviors can be derived to provide a metric relatively independent of participant characteristics such as age and language skills (Gotham et al., 2009; Hus et al., 2014; Janvier et al., 2022).

Autism Diagnostic Interview-Revised (ADI-R). The ADI-R is a clinician-administered interview conducted with caregivers to gather an in-depth developmental history and assist in diagnosing autism (Lord et al., 1994). Responses are scored from 0 (typical behavior) to 3 (most atypical behavior) and assess three core characteristics of autism: communication and language skills, social interaction, and restricted and repetitive behaviors. For this study, the social interaction domain was analyzed.

Social Communication Questionnaire (SCQ). The SCQ is a 40-item autism screening questionnaire modeled after the ADI-R and designed for caregivers to complete independently (Rutter et al., 2003). Scores range from 0 to 39. Typically a cutoff score of ⩾15 is taken to be suggestive that the individual is likely to be on the autism spectrum; to increase sensitivity and identify more children who may be autistic, SEED researchers considered a lower cutoff score of 11 (Wiggins et al., 2007). This instrument was

Table 1. Description of Instruments and Variables Used.

Measure	Domain/subdomain	Type	Score type	Score description	Study threshold for substantial challenges (description)
Motor skills					
MSEL	Fine motor skills	Clinician assessment	*T*-score	*M* (*SD*): 50 (10) Range: 20–80	⩽30 (2 SDs below the mean)
Vineland-II	Motor skills	Caregiver interview	Standard score	*M* (*SD*): 100 (15) Range: 20–160	⩽70 (2 SDs below the mean)
	Fine motor	Caregiver interview	V-scale score	*M* (*SD*): 15 (3) Range: 1–24	⩽9 (2 SDs below the mean)
	Gross motor	Caregiver interview	V-scale score	*M* (*SD*): 15 (3) Range: 1–24	⩽9 (2 SDs below the mean)
Social skills					
ADI-R	Social interaction	Caregiver interview	Raw scores	Range: 0–30	⩾10 (autism cutoff)
ADOS	Social affect	Clinician assessment	Calibrated severity score	Range: 1–10	⩾5 (moderate to high evidence of autism)
SCQ	Total score	Caregiver questionnaire	Raw scores	Range: 0–39	⩾11 (SEED autism cutoff[a])
SRS	Total Score	Caregiver questionnaire	*T*-score	Range: 30–90	⩾60 (mild to severe risk of autism)
Vineland-II	Socialization	Caregiver interview	Standard score	*M* (*SD*): 100 (15) Range: 20–160	⩽70 (2 SDs below the mean)
Early learning delays					
MSEL	Visual reception	Clinician assessment	*T*-score	*M* (*SD*): 50 (10)	⩽30 (2 SDs below the mean)

MSEL: Mullen Scales of Early Learning; SD: standard deviation; Vineland-II: Vineland Adaptive Behavior Scales, Second Edition; ADI-R: Autism Diagnostic Interview-Revised; ADOS: Autism Diagnostic Observation Schedule; SCQ: Social Communication Questionnaire; SRS: Social Responsiveness Scale; SEED: Study to Explore Early Development.

[a]While a cutoff of 15 is typically used, to increase sensitivity, SEED analysts lowered the SCQ cutoff score to 11.

administered to the primary caregiver at the initial invitation and eligibility assessment call.

Social Responsiveness Scale (SRS). The SRS is a 65-item caregiver-report questionnaire designed to assess the severity of social impairments associated with autism in everyday social settings (Constantino & Gruber, 2005, 2012). It evaluates behaviors in five domains, including social awareness, social cognition, social communication, social motivation, and restricted interests or repetitive behaviors.

Vineland-II Socialization Domain. The Vineland-II socialization domain includes three subdomains: interpersonal relationships, which measures how the child interacts with others; play and leisure time, which assesses how the child uses their playtime; and coping skills, which examines how the child demonstrates responsibility as well as their sensitivity to others.

Additional Variables

Mullen Scales of Early Learning Visual Reception Domain. Although the MSEL provides a global composite measure of cognitive ability derived from its four domains, fine motor skills are included in the composite, and we therefore considered only the MSEL visual reception domain score in analyses (Mullen, 1995). This domain assesses a child's ability to process and understand visual information and serves as an independent proxy for nonverbal cognitive ability. Prior research suggests that nonverbal scores remain more stable in young autistic children and may better capture cognitive ability in those with early language delays that do not persist beyond the preschool years (Akshoomoff, 2006; Ellis Weismer et al., 2021; Furnier et al., 2024). A *T*-score ($M = 50$, $SD = 10$) was used for analysis, and nonverbal cognitive ability was stratified using a threshold score of ⩽30 (two SDs below the mean), distinguishing between very low nonverbal cognitive ability and higher (Table 1).

Sociodemographic Variables. Sociodemographic covariates were collected during the caregiver interview. Household income level was defined as an ordinal variable, calculated as the ratio of caregiver-reported household income from the previous 12 months relative to the federal poverty level (FPL). The FPL is the income threshold used to determine eligibility for public assistance programs like Medicaid and Children's Health Insurance Program and takes into account both household income and size. Because the FPL is a measure specific to the US, these categories should be interpreted as indicators of relative household economic resources. Income categories included ⩽138% FPL (lowest income), 138%–250%, 250%–400%, and ⩾400% FPL (highest income). Child sex, race, and ethnicity were also derived from the caregiver interview.

Statistical Analysis

The percentage of missing data was described in eTable 1 in Supplemental Material and addressed using multiple imputation by chained equations. The imputation model included all regression model variables as well as auxiliary variables correlated with any analytic model variable (Spearman correlation coefficient ⩾ 0.20). Variables were imputed sequentially, from least to most missing, to generate 50 imputed datasets after a 50-iteration burn-in. Study sample characteristics were reported as numbers of observations (percentage) for the overall sample and for participants with motor difficulties, as indicated by any motor score. To compare the frequency of significant motor challenges across sociodemographic characteristics prevalence ratios (PRs) and 95% confidence intervals (CIs) were calculated. Summary statistics were computed for each of the motor and social skill measures, both overall and stratified by the MSEL visual reception domain score ⩽30 or >30. Mean differences and 95% confidence intervals comparing motor and social skill measures between children with MSEL visual reception scores ⩽30 and >30 were estimated using linear regression models. The percentage of children with substantial motor challenges was stratified by motor measure and by race and ethnicity in eTable 2 in Supplemental Material to examine potential differences across groups.

To estimate associations between measures of motor and social skills, we used linear regression models with social skills as the dependent variable and motor skills as the primary predictor of interest, resulting in 20 unadjusted and 20 covariate-adjusted models. For each model, we examined a potential curvilinear relationship with the inclusion of a quadratic motor skills term. Model form (linear vs quadratic) was selected based on model fit indices Akaike Information Criterion and Bayesian Information Criterion. Motor skill variables were centered on the average of the first and third quartiles and scaled by the interquartile range (IQR) to aid in interpretability of the coefficients. As a result, estimated beta (β) coefficients represent the change in social skills scores associated with a one-IQR increase in motor skills scores and can be compared between motor instruments. Adjusted beta coefficients (aβ) were estimated after controlling for the following covariates: child's sex, race and ethnicity, household income relative to the FPL, MSEL visual reception *T*-score, and SEED study site. Using centered and scaled motor skills scores, we created a scatterplot matrix to visualize the associations between motor and social skills. We retained the model fit information from above to determine if a linear or quadratic line should be plotted for the associations between motor and social skills. In addition, we examined correlations within motor skill measures (eFigure 1 in Supplemental Material) and within social skill measures (eFigure 2 in Supplemental Material) using separate scatterplot matrices. To address the potential of an increased

Table 2. Key Sociodemographic Characteristics of the Analytic Sample, Study to Explore Early Development Autistic Children, 2007 to 2020.

	Overall, *n* (column %)	Motor difficulties indicated by any motor score, *n* (row %)	Prevalence ratio, (95% CI)
Total *N*	2,039	1,373 (67.3)	–
Child sex			
Female	388 (19.0)	267 (68.8)	1.03 (0.95, 1.11)
Male	1,651 (81.0)	1,106 (67.0)	1 (Reference)
Child race and ethnicity			
Asian or Pacific Islander, NH	104 (5.1)	70 (67.3)	1.07 (0.93, 1.24)
Black, NH	434 (21.3)	322 (74.1)	1.18 (1.10, 1.27)
Hispanic	355 (17.4)	246 (69.3)	1.10 (1.01, 1.20)
Other, NH[a]	226 (11.1)	158 (70.1)	1.12 (1.01, 1.24)
White, NH	919 (45.1)	576 (62.7)	1 (Reference)
Child age in years, mean (95% CI)	4.60 (4.57, 4.63)	4.55 (4.51, 4.59)	–
Minimum, maximum	2.39, 5.88	2.48, 5.88	
MSEL Visual Reception			
$\leqslant$30[b]	1,058 (51.9)	990 (93.6)	2.40 (2.21, 2.60)
$>$30[b]	981 (48.1)	383 (39.0)	1 (Reference)
Household income relative to the FPL			
$\leqslant$138%	575 (28.2)	436 (75.9)	1.21 (1.12, 1.31)
138%–250%	398 (19.5)	276 (69.4)	1.11 (1.01, 1.21)
250%–400%	460 (22.6)	280 (61.0)	0.97 (0.88, 1.07)
$\geqslant$400%	606 (29.7)	380 (62.7)	1 (Reference)
Study site			
California	235 (11.5)	145 (61.6)	0.94 (0.83, 1.06)
Colorado	354 (17.4)	220 (62.2)	0.95 (0.85, 1.06)
Georgia	383 (18.8)	251 (65.5)	1 (Reference)
Maryland	343 (16.8)	256 (74.8)	1.14 (1.04, 1.26)
Missouri	121 (5.9)	87 (71.9)	1.10 (0.96, 1.25)
North Carolina	306 (15.0)	219 (71.5)	1.09 (0.99, 1.21)
Pennsylvania	205 (10.1)	130 (63.3)	0.97 (0.85, 1.10)
Wisconsin	92 (4.5)	65 (70.7)	1.08 (0.92, 1.26)

Note. CI: confidence interval; FPL: federal poverty level; MSEL: Mullen Scales of Early Learning; *n*: sample size; NH: non-Hispanic.
[a]Due to small sample sizes, those reporting American Indian/Alaskan Native, another race, or more than one race, were combined to form the non-Hispanic Other category.
[b]An MSEL visual reception score $\leqslant$30 was chosen as cut points since this threshold is two standard deviations below the mean.

false positive rate due to multiple comparisons, a Bonferroni correction was applied to our regression results; with 40 total models (including both unadjusted and covariate-adjusted), a corrected alpha of .00125 was used to assess significance.

Statistical analyses were conducted using SAS Version 9.4 (SAS Institute Inc.). All tests of statistical significance were two-tailed, and, unless otherwise noted, a p-value $<$ .05 was considered statistically significant.

Results

The study sample included 2,039 autistic children with 81.0% males, 45.1% non-Hispanic (NH) White, and 29.7% from households with incomes $\geqslant$ 400% of the FPL (Table 2). Compared to NH White children, substantial motor difficulties on any instrument were more prevalent among NH Black children (PR = 1.18; 95% CI: 1.10–1.27), Hispanic children (PR = 1.10; 95% CI: 1.01–1.20), and children in the NH Other category (PR = 1.12; 95% CI: 1.01–1.24). When results were stratified by race and motor skill measure, the fine motor skill measures followed a similar pattern (eTable 2 in Supplemental Material). However, the Vineland-II gross motor skills subdomain suggested that Hispanic children had the highest percentage of substantial gross motor challenges (16.5%), followed by NH White children (14.6%), NH Other children (13.7%), NH Black children (12.9%), and finally, NH Asian children (9.4%). The frequency of substantial motor challenges did not differ by sex (PR = 1.03; 95% CI: 0.95–1.11), but they were more common in children with well below average nonverbal cognitive ability (MSEL T-score $\leqslant$ 30) than higher nonverbal cognitive ability (PR = 2.40; 95% CI: 2.21–2.60). In addition, children from families with household incomes ≤138% of the FPL had more motor challenges compared with those from families with household incomes >400% of the FPL (PR = 1.21; 95% CI: 1.12–1.31).

Motor Skills

The highest percentage of children with substantial motor skill challenges was observed in the MSEL fine motor domain (63.4%), while the lowest percentage was identified on the Vineland-II gross motor subdomain (14.2%; Table 3). A consistent pattern was observed across instruments regardless of nonverbal cognitive level, but substantial motor skill difficulties were more common among children with MSEL visual reception domain *T*-scores ≤ 30 (21.2% to 92.7%) than >30 (6.7%–31.8%). As expected, the Vineland-II fine and gross motor subdomains were strongly correlated with the Vineland-II motor skills domain derived from them. Correlations between the MSEL fine motor domain and Vineland-II motor domains were moderate (eFigure 1 in Supplemental Material).

Social Skills

The percentage of children identified as having substantial social difficulties ranged from 95.4% (ADI-R social interaction domain) to 49.7% (Vineland-II socialization domain; Table 3). After stratifying by nonverbal cognitive status, substantial social skill difficulties were more common among children with MSEL visual reception *T*-score ≤ 30 (70.1% to 97.9%) than >30 (27.8%–92.7%). All social skills measures showed moderate correlations with one another, apart from the ADOS social affect domain, which demonstrated no correlation with any of the other social skill measures (eFigure 2 in Supplemental Material).

Associations Between Motor and Social Skills

We examined associations between four motor skill measures and five social skill measures, using both unadjusted and covariate-adjusted linear regression models (Table 4). Results varied across social skill measures, with some consistent trends. As hypothesized, higher motor skill scores were associated with fewer social difficulties and greater social skills. Specifically, motor skills scores were negatively associated with scores on the ADI-R, SCQ, and SRS, and positively associated with scores on the Vineland-II socialization domain, even after adjusting for potential confounders. The ADI-R social interaction domain showed significant linear associations with each of the motor skill variables, with statistically significant positive squared terms for each motor skill variable aside from the Vineland-II gross motor skills subdomain. Similar strong associations were observed between each of the motor skill variables and both the SCQ and SRS total scores. Associations with the Vineland-II socialization domain were significant across all linear and squared motor skill measures, with the strongest association observed for the Vineland-II fine motor skills domain (aβ = 8.01; 95% CI: 7.32–8.69). In contrast, no significant associations were found between the ADOS social affect domain and any motor skill measures in unadjusted or covariate-adjusted models. The significance of the squared motor skills terms in several models suggests the possibility of a nonlinear relationship, in which the association between motor skills and social interaction is stronger at lower motor abilities and diminishes at higher levels (Figure 1). Although covariate adjustment attenuated many associations across measures of motor and social skills, particularly for models of MSEL fine motor skills, key findings remained significant.

Discussion

Motor and social skill challenges are common in preschool-aged autistic children and may be closely linked, suggesting that targeting motor skills could support social development (Haghighi et al., 2023; Ketcheson et al., 2017; Sansi et al., 2021). In this study, over two-thirds of children demonstrated substantial motor challenges on at least one assessment. Fine motor skill difficulties were more prevalent than gross motor skill difficulties, and motor challenges were consistently more common among children with lower cognitive ability. However, even autistic children with higher cognitive skills exhibited motor difficulties, indicating that these challenges are not solely driven by cognitive delays (Bhat, 2024; Licari et al., 2020; Pokoski et al., 2025; Reynolds et al., 2022). This study enhances prior work by highlighting motor skills as an important domain associated with social functioning in practical, everyday contexts (as measured by the Vineland-II) and related to the autism phenotype (as measured by the ADI-R, SCQ, and SRS). Parents, professionals, and others can use these findings to encourage joint developmental surveillance, screening, and treatment of motor and social skills in young autistic children, as indicated. Further research is needed to understand the longitudinal nature of these relationships and whether interventions targeting motor skills could improve social functioning.

Fine motor skill challenges in our sample varied by assessment instrument, with 31.1% of children classified as having substantial challenges based on the Vineland-II and 63.4% based on the MSEL. The discrepancy between the percentage of children classified as having substantial motor challenges on the MSEL versus the Vineland-II may be due to inherent differences in these instruments (eFigure 1 in Supplemental Material). The MSEL evaluates motor abilities through clinician observation and administration of structured tasks. In contrast, the Vineland-II is a caregiver-report measure in which parents rate their child's

Table 3. Summary Statistics for Measures of Social and Motor Skills; Study to Explore Early Development Autistic Children, 2007–2020.

	Overall			MSEL visual reception ⩽ 30 (n = 1,058)			MSEL visual reception > 30 (n = 981)			
	Mean (95% CI)	Range	n (%) with substantial challenges[a]	Mean (95% CI)	Range	n (%) with substantial challenges[a]	Mean (95% CI)	Range	n (%) with substantial challenges[a]	Mean difference (99.9% CI)
Motor skills										
MSEL Fine Motor	28.9 (28.4, 29.4)	20–80	1,293 (63.4)	21.8 (21.5, 22.1)	20–52	981 (92.7)	36.7 (35.9, 37.4)	20–80	312 (31.8)	14.9 (14.1, 15.7)*
Vineland-II Motor Skills	79.1 (78.5, 79.7)	37–124	587 (28.8)	73.4 (72.7, 74.1)	37–124	465 (43.9)	85.3 (84.5, 86.0)	49–124	122 (12.4)	11.9 (10.9, 12.9)*
Vineland-II Fine Motor	11.18 (11.1, 11.3)	2–20	631 (31.0)	9.9 (9.8, 10.0)	2–20	509 (48.1)	12.6 (12.4, 12.7)	4–20	122 (12.5)	2.7 (2.5, 2.9)*
Vineland-II Gross Motor	11.9 (11.8, 12.0)	4–20	290 (14.2)	11.3 (11.2, 11.5)	4–20	224 (21.2)	12.6 (12.5, 12.7)	5–20	65 (6.7)	1.3 (1.1, 1.5)*
Social skills										
ADOS CSS of Social Affect	5.4 (5.3, 5.4)	1–9	1,453 (71.3)	5.3 (5.2, 5.4)	1–9	768 (72.6)	5.5 (5.4, 5.6)	1–9	685 (69.8)	0.2 (0.1, 0.3)
ADI-R Social Interaction	18.3 (18.1, 18.6)	8–30	1,945 (95.4)	20.1 (19.8, 20.4)	8–30	1,036 (97.9)	16.4 (16.1, 16.7)	8–30	909 (92.7)	−3.7 (−4.2, −3.2)*
SCQ Total Score	17.6 (17.4, 17.9)	0–36	1,826 (89.6)	19.3 (18.9, 19.6)	3–36	1,009 (95.4)	15.9 (15.5, 16.3)	0–35	817 (83.3)	−3.4 (−3.9, −2.9)*
SRS Total *T*-score	72.6 (72.1, 73.1)	41–90	1,795 (88.0)	74.7 (74.0, 75.3)	41–90	979 (92.6)	70.4 (69.7, 71.1)	41–90	816 (83.2)	−4.3 (−5.2, −3.3)*
Vineland-II Socialization	71.7 (71.2, 72.3)	44–112	1,014 (49.7)	66.1 (65.5, 66.7)	44–112	742 (70.1)	77.8 (77.1, 78.5)	48–112	272 (27.8)	11.6 (10.7, 12.6)*

Note. ADI-R: Autism Diagnostic Interview, Revised; ADOS: Autism Diagnostic Observation Schedule; CI: confidence interval; CSS: calibrated severity score; MSEL: Mullen Scales of Early Learning; *n*: sample size; SCQ: Social Communication Questionnaire; SRS: Social Responsiveness Scale; Vineland-II: Vineland Adaptive Behavior Scales, Second Edition.
[a]Refer to Table 1 for the specific scores associated with substantial challenges for each instrument used.
*$p < .00125$.

Table 4. Associations Between Motor Skills Scores and Social Skills Scores, Study to Explore Early Development Autistic Children, 2007–2020[a].

		Primary predictor of interest							
		Vineland-II motor skills		Vineland-II fine motor		Vineland-II gross motor		MSEL fine motor	
		Linear	Squared	Linear	Squared	Linear	Squared	Linear	Squared
Outcome	Model[b]	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)
ADI-R Social Interaction	Unadj.	**−2.98 (−3.30, −2.65)**	**0.64 (0.30, 0.98)**	**−3.14 (−3.49, −2.79)**	**1.11 (0.73, 1.49)**	**−2.27 (−2.60, −1.94)**	N/A	**−3.26 (−3.79, −2.73)**	**1.22 (0.73, 1.72)**
	Adj.	**−2.09 (−2.45, −1.73)**	**0.67 (0.34, 1.00)**	**−2.11 (−2.49, −1.72)**	**1.12 (0.75, 1.48)**	**−1.61 (−1.94, −1.28)**	N/A	−0.52 (−1.01, −0.04)	N/A
ADOS Social Affect	Unadj.	0.10 (0.01, 0.19)	N/A	0.14 (0.04, 0.23)	N/A	0.06 (−0.03, 0.15)	N/A	0.09 (−0.01, 0.18)	N/A
	Adj.	0.02 (−0.08, 0.12)	N/A	0.04 (−0.06, 0.15)	N/A	0.02 (−0.08, 0.11)	N/A	−0.07 (−0.2, 0.13)	N/A
SCQ Total Score	Unadj.	**−2.74 (−3.08, −2.40)**	N/A	**−2.61 (−2.96, −2.25)**	N/A	**−2.24 (−2.58, −1.89)**	N/A	**−2.97 (−3.53, −2.42)**	**1.09 (0.58, 1.61)**
	Adj.	**−1.98 (−2.36, −1.60)**	N/A	**−1.72 (−2.12, −1.31)**	N/A	**−1.65 (−2.00, −1.30)**	N/A	−0.64 (−1.16, −0.13)	N/A
SRS Total Score	Unadj.	**−4.66 (−5.29, −4.03)**	N/A	**−4.84 (−5.53, −4.15)**	**1.55 (0.80, 2.30)**	**−3.92 (−4.55, −3.28)**	N/A	**−2.71 (−3.41, −2.01)**	N/A
	Adj.	**−3.94 (−4.65, −3.24)**	N/A	**−4.02 (−4.80, −3.24)**	**1.53 (0.79, 2.27)**	**−3.15 (−3.81, −2.49)**	N/A	−0.69 (−1.67, 0.29)	N/A
Vineland–II Socialization	Unadj.	**10.16 (9.58, 10.75)**	**−1.16 (−1.76, −0.55)**	**10.55 (9.92, 11.18)**	**−1.53 (−2.21, −0.85)**	**7.98 (7.29, 8.67)**	**−1.25 (−1.86, −0.64)**	**11.17 (10.15, 12.18)**	**−4.07 (−5.01, −3.13)**
	Adj.	**7.84 (7.22, 8.46)**	**−1.11 (−1.69, −0.54)**	**8.01 (7.32, 8.69)**	**−1.50 (−2.15, −0.86)**	**5.94 (5.29, 6.58)**	**−1.08 (−1.62, −0.53)**	**6.33 (5.08, 7.58)**	**−2.92 (−3.83, −2.01)**

Note. Bolded number indicates $p < .00125$. Adj: covariate-adjusted model; ADI-R: Autism Diagnostic Interview, Revised; ADOS: Autism Diagnostic Observation Schedule; CI: confidence interval; MSEL: Mullen Scales of Early Learning; SCQ: Social Communication Questionnaire; SRS: Social Responsiveness Scale; Unadj: unadjusted model; Vineland-II: Vineland Adaptive Behavior Scales, Second Edition.

[a]Motor skill scores were centered at the average of the first and third quartiles and scaled by the interquartile range (IQR), so beta coefficients represent the change in social skills scores associated with a one-IQR increase in motor skills scores.

[b]Unadjusted models include the linear motor skill score and the squared motor skill score if model fit indices suggested a curvilinear relationship. Covariate-adjusted models include child sex, race and ethnicity, household income relative to the federal poverty level, MSEL visual reception domain *T*-score, and SEED study site.

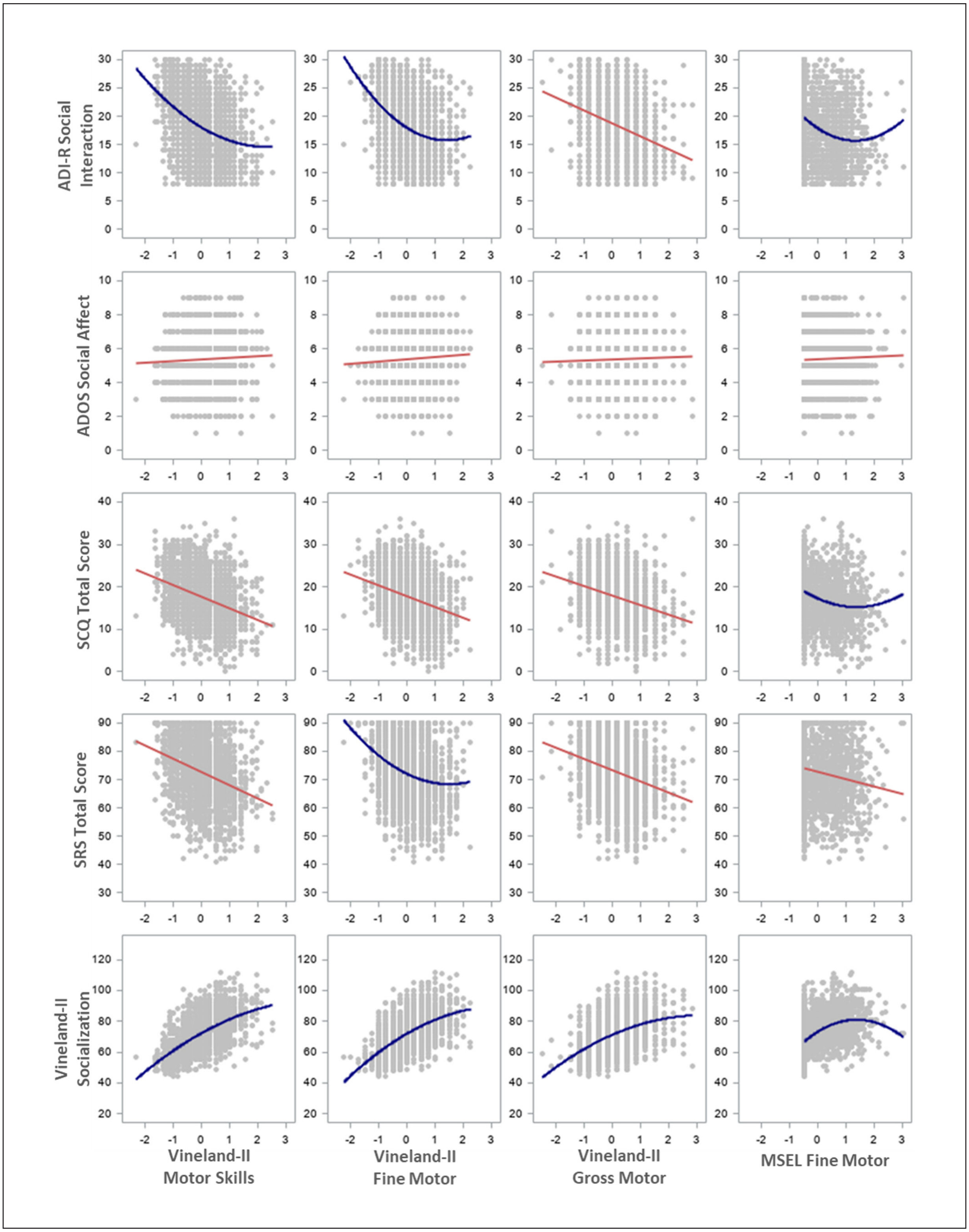

Figure 1. Scatterplot matrix for the association between motor and social skill variables. Study to explore early development autistic children, 2007–2020.[a]

Note. ADI-R: Autism Diagnostic Interview, Revised; ADOS: Autism Diagnostic Observation Schedule; MSEL: Mullen Scales of Early Learning; SCQ: Social Communication Questionnaire; SRS: Social Responsiveness Scale; Vineland-II: Vineland Adaptive Behavior Scales, Second Edition.

[a] Motor skill scores were centered at the average of the first and third quartiles and scaled by the interquartile range (IQR), represented on the x-axis. Dark blue lines represent the quadratic regression line and red lines indicate linear regression lines (see Table 4 and "Methods" for model selection details).

everyday use of motor skills on a scale from "never performed" to "usually performed without help." Because the Vineland-II focuses on functional skills in familiar contexts, it may classify fewer children as having substantial challenges than a structured, performance-based clinician assessment in an unfamiliar environment. These distinctions are important because motor assessments may lead to different conclusions about a child's motor profile depending on whether observed performance or functional use of skills is prioritized. Considering both perspectives may provide a more comprehensive understanding of motor strengths and needs in autistic children.

Social skill challenges also varied by assessment instrument, ranging from 49.6% classified as having substantial challenges on the Vineland-II socialization domain to 95.3% based on the ADI-R social interaction subscale. These differences likely stem from the distinct constructs each measure targets. The Vineland-II focuses on everyday social functioning, whereas the ADI-R assesses autism-specific social challenges. In addition, the ADI-R, SCQ, and ADOS contributed to the autism case definition, while the SRS and Vineland-II were independent measures of social skills. Interestingly, the ADOS social affect domain did not show significant correlations with the other social skill measures, which may reflect differences in assessment context and method of reporting. The ADOS is a clinician-administered, semi-structured behavioral assessment conducted during a brief standardized session, whereas the Vineland-II and SRS capture caregiver-reported everyday social functioning. The calibrated severity scores of the ADOS were also designed to be less influenced by child characteristics than raw scores or other total scores (Hus et al., 2014), which may contribute to the lack of observed correlations. These distinctions underscore that social measures vary in whether they capture functional skills, autism-specific symptoms, or performance during a structured interaction. For clinical and research applications, integrating information across these domains may help capture both functional and autism-specific social challenges when assessing autistic children and improve the precision of treatment planning and outcome monitoring.

Previous literature suggests that developmental milestone indicators most often focus on physical development and less frequently on social development (Ryberg et al., 2022; Zubler et al., 2022), perhaps due to the relative objectivity of motor skills such as walking or crawling compared with the subjectivity of social skills such as joint attention or social reciprocity behaviors. In the context of our findings demonstrating substantial motor challenges in autistic individuals and their association with social skills, this emphasis on motor development is particularly salient. Parents of autistic children who exhibited motor delays reported developmental concerns at a significantly younger age compared with those without motor delays (Guinchat et al., 2012; Matheis et al., 2017), and studies of the infant siblings of autistic children show that parents more often report early concerns about motor development (Posar & Visconti, 2022; Sacrey et al., 2015; West, 2019). Together, these findings indicate that motor delays are both common and readily recognized, positioning motor development as an important and accessible point for early autism evaluation. Our results therefore suggest that motor development may represent an important component of comprehensive autism evaluations.

In these analyses, the prevalence of motor challenges varied by race and ethnicity, with NH Black, Hispanic, and NH Other race children more often identified as having substantial motor difficulties based on parent report or clinician observation. This aligns with prior research showing that NH Black parents report motor concerns as the second most common developmental concern after communication, while NH White parents report it as third, following communication and social concerns (Donohue et al., 2019). Thus, NH Black and Latino families may be recognizing motor problems more than social or communication problems and could benefit from targeted education on typical social development. In addition, previous studies have suggested that autistic children from disadvantaged socioeconomic backgrounds, including those from lower-income households, are less likely to access early intervention programs and other autism-related services (Shenouda et al., 2022; Smith et al., 2020). Our finding that children from lower-income families experience greater motor challenges could reflect these disparities in service access, particularly if they did not receive therapies focused on motor development. Although prior studies have previously found motor difficulties to be more common in young autistic girls than boys (Gabis et al., 2020), we did not observe significant sex differences in our sample. This could reflect differences in sampling, measurement, or overall study design.

Limitations

Despite leveraging the large, diverse, community-based SEED sample, this study has important limitations to consider. As our study is based on a U.S. sample, the results are not necessarily generalizable across cultural and geographic contexts due to variation in early identification practices, service access, and local expectations of development. These differences highlight the need for culturally sensitive assessments and caution when generalizing or comparing findings across populations. In addition, measurement bias could have been introduced since the SCQ, SRS, Vineland-II, and ADI-R are all caregiver-reported measures. While parents are typically reliable reporters of their child's adaptive behaviors (Miller et al., 2017), the retrospective nature of some measures, particularly the ADI-R, may introduce recall bias (Grzadzinski et al., 2016). In addition, common method variance may inflate associations between motor and social skill variables that were both caregiver-reported.

This concern may be particularly relevant for models examining the associations between Vineland-II socialization scores and Vineland-II motor skill scores. However, strong associations were also observed between the Vineland-II socialization score and the MSEL fine motor skills score, the latter of which is a clinician-administered assessment, suggesting that caregiver-reporting alone does not account for the relationships. In addition, we attempted to mitigate potential measurement error by incorporating multiple standardized, validated motor and social skills instruments, including clinician-administered assessments that were conducted by research-reliable study clinicians. Missing data could also have introduced bias, although we used multiple imputation to address this issue. While multiple imputation assumes that data are missing at random, this assumption, though reasonable, cannot be statistically verified. Furthermore, the measures used in this study have not been normed with non-English speaking participants and all measures were obtained around the same time, so causality cannot be determined. Finally, selection bias may have occurred, since families who consented to participate may not be representative of all families with autistic children, potentially limiting the generalizability of the findings.

Conclusion

This study documents and quantifies the significant association between motor and social skills in preschool-aged autistic children and points to the importance of considering motor development in early autism evaluations. Using multiple validated, standardized measures, we found that social skills were significantly linked to motor skills, though the strength of these associations varied by measure. Future research could use longitudinal designs to better inform potential causality and assessment of whether early motor skills predict later social development. Increasing awareness among clinicians and caregivers about the relevance of motor skills in autism may enhance early intervention efforts and promote more equitable access to services, ultimately improving developmental outcomes for autistic children.

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Ethical Considerations

The SEED protocol was approved by the CDC Institutional Review Board (IRB) and IRBs at each study site. The studies were conducted in accordance with the local legislation and institutional requirements.

Consent to Participate

Written informed consent for participation in SEED was provided by the participants' legal guardians.

Consent for Publication

Not applicable.

Author Contributions

Olivia M. Pokoski: Conceptualization; Formal analysis; Methodology; Writing – original draft; Writing – review & editing.
Hideko Engel: Formal analysis; Validation; Writing – review & editing.
Sarah M. Furnier: Formal analysis; Validation; Writing – review & editing.
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Maureen S. Durkin: Conceptualization; Funding acquisition; Investigation; Methodology; Supervision; Writing – review & editing.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available to ensure participant confidentiality.

Supplemental Material

Supplemental material for this article is available online.

References

Akshoomoff, N. (2006). Use of the Mullen Scales of Early Learning for the assessment of young children with Autism Spectrum Disorders. *Child Neuropsychology*, *12*(4–5), 269–277. https://doi.org/10.1080/09297040500473714

Azad, G., Holingue, C., Pfeiffer, D., Dillon, E., Reetzke, R., Kalb, L., Menon, D., Hong, J. S., & Landa, R. (2022). The influence of race on parental beliefs and concerns during an autism diagnosis: A mixed-method analysis. *Autism*, *26*(5), 1176–1187. https://doi.org/10.1177/13623613211044345

Bhat, A. N. (2021). Motor impairment increases in children with autism spectrum disorder as a function of social communication, cognitive and functional impairment, repetitive behavior severity, and comorbid diagnoses: A SPARK study report. *Autism Research*, *14*(1), 202–219. https://doi.org/10.1002/aur.2453

Bhat, A. N. (2024). Validating motor delays across the developmental coordination disorder-questionnaire and the Vineland adaptive behavior scales (VABS) in children with autism spectrum disorder (ASD): A SPARK dataset analysis. *Autism Research*, *17*(10), 2079–2091. https://doi.org/10.1002/aur.3189

Constantino, J. N., & Gruber, C. P. (2005). *Social Responsiveness Scale*. Western Psychological Services.

Constantino, J. N., & Gruber, C. P. (2012). *Social Responsiveness Scale, Second Edition*. Western Psychological Services.

Craig, F., Crippa, A., Ruggiero, M., Rizzato, V., Russo, L., Fanizza, I., & Trabacca, A. (2021). Characterization of Autism Spectrum Disorder (ASD) subtypes based on the relationship between motor skills and social communication abilities. *Human Movement Science*, *77*, Article 102802. https://doi.org/10.1016/j.humov.2021.102802

Donohue, M. R., Childs, A. W., Richards, M., & Robins, D. L. (2019). Race influences parent report of concerns about symptoms of autism spectrum disorder. *Autism*, *23*(1), 100–111. https://doi.org/10.1177/1362361317722030

Ellis Weismer, S., Rubenstein, E., Wiggins, L., & Durkin, M. S. (2021). A preliminary epidemiologic study of social (pragmatic) communication disorder relative to autism spectrum disorder and developmental disability without social communication deficits. *Journal of Autism and Developmental Disorders*, *51*(8), 2686–2696. https://doi.org/10.1007/s10803-020-04737-4

Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of Autism and Developmental Disorders*, *40*(10), 1227–1240. https://doi.org/10.1007/s10803-010-0981-3

Furnier, S. M., Ellis Weismer, S., Rubenstein, E., Gangnon, R., Rosenberg, S., Nadler, C., Wiggins, L. D., & Durkin, M. S. (2024). Using adaptive behavior scores to convey level of functioning in children with autism spectrum disorder: Evidence from the Study to Explore Early Development. *Autism*, *28*(5), 1135–1149. https://doi.org/10.1177/13623613231193194

Gabis, L. V., Attia, O. L., Roth-Hanania, R., & Foss-Feig, J. (2020). Motor delay – An early and more common "red flag" in girls rather than boys with autism spectrum disorder. *Research in Developmental Disabilities*, *104*, Article 103702. https://doi.org/10.1016/j.ridd.2020.103702

Gotham, K., Pickles, A., & Lord, C. (2009). Standardizing ADOS scores for a measure of severity in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*(5), 693–705. https://doi.org/10.1007/s10803-008-0674-3

Grzadzinski, R., Dick, C., Lord, C., & Bishop, S. (2016). Parent-reported and clinician-observed autism spectrum disorder (ASD) symptoms in children with attention deficit/hyperactivity disorder (ADHD): Implications for practice under DSM-5. *Molecular Autism*, *7*, Article 7. https://doi.org/10.1186/s13229-016-0072-1

Guinchat, V., Chamak, B., Bonniau, B., Bodeau, N., Perisse, D., Cohen, D., & Danion, A. (2012). Very early signs of autism reported by parents include many concerns not specific to autism criteria. *Research in Autism Spectrum Disorders*, *6*(2), 589–601. https://doi.org/10.1016/j.rasd.2011.10.005

Haghighi, A. H., Broughani, S., Askari, R., Shahrabadi, H., Souza, D., & Gentil, P. (2023). Combined physical training strategies improve physical fitness, behavior, and social skills of autistic children. *Journal of Autism and Developmental Disorders*, *53*(11), 4271–4279. https://doi.org/10.1007/s10803-022-05731-8

Holloway, J. M., & Long, T. M. (2019). The interdependence of motor and social skill development: Influence on participation. *Physical Therapy*, *99*(6), 761–770. https://doi.org/10.1093/ptj/pzz025

Hus, V., Gotham, K., & Lord, C. (2014). Standardizing ADOS domain scores: Separating severity of social affect and restricted and repetitive behaviors. *Journal of Autism and Developmental Disorders*, *44*(10), 2400–2412. https://doi.org/10.1007/s10803-012-1719-1

Iverson, J. M., Shic, F., Wall, C. A., Chawarska, K., Curtin, S., Estes, A., Gardner, J. M., Hutman, T., Landa, R. J., Levin, A. R., Libertus, K., Messinger, D. S., Nelson, C. A., Ozonoff, S., Sacrey, L. R., Sheperd, K., Stone, W. L., Tager-Flusberg, H. B., Wolff, J. J., . . .Young, G. S. (2019). Early motor abilities in infants at heightened versus low risk for ASD: A Baby Siblings Research Consortium (BSRC) study. *Journal of Abnormal Psychology*, *128*(1), 69–80. https://doi.org/10.1037/abn0000390

Janvier, D., Choi, Y. B., Klein, C., Lord, C., & Kim, S. H. (2022). Brief report: Examining test-retest reliability of the Autism Diagnostic Observation Schedule (ADOS-2) calibrated severity scores (CSS). *Journal of Autism and Developmental Disorders*, *52*(3), 1388–1394. https://doi.org/10.1007/s10803-021-04952-7

Kangarani-Farahani, M., Malik, M. A., & Zwicker, J. G. (2024). Motor impairments in children with autism spectrum disorder: A systematic review and meta-analysis. *Journal of Autism and Developmental Disorders*, *54*(5), 1977–1997. https://doi.org/10.1007/s10803-023-05948-1

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child*, *2*, 217–350.

Ketcheson, L., Hauck, J., & Ulrich, D. (2017). The effects of an early motor skill intervention on motor skills, levels of physical activity, and socialization in young children with autism spectrum disorder: A pilot study. *Autism*, *21*(4), 481–492. https://doi.org/10.1177/1362361316650611

Licari, M. K., Alvares, G. A., Varcin, K., Evans, K. L., Cleary, D., Reid, S. L., Glasson, E. J., Bebbington, K., Reynolds, J. E., Wray, J., & Whitehouse, A. J. O. (2020). Prevalence of motor difficulties in autism spectrum disorder: Analysis of a population-based cohort. *Autism Research*, *13*(2), 298–306. https://doi.org/10.1002/aur.2230

Lim, Y. H., Licari, M., Spittle, A. J., Watkins, R. E., Zwicker, J. G., Downs, J., & Finlay-Jones, A. (2021). Early motor function of children with autism spectrum disorder: A systematic review. *Pediatrics*, *147*(2), Article e2020011270. https://doi.org/10.1542/peds.2020-011270

Lloyd, M., Macdonald, M., & Lord, C. (2013). Motor skills of toddlers with autism spectrum disorders. *Autism*, *17*(2), 133–146. https://doi.org/10.1177/1362361311402230

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (1999). *Autism Diagnostic Observation Schedule*. Western Psychological Services.

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism Diagnostic Observation Schedule, Second Edition*. Western Psychological Services.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685. https://doi.org/10.1007/BF02172145

MacDonald, M., Lord, C., & Ulrich, D. (2013). The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. *Res Autism Spectr Disord*, *7*(11), 1383–1390. https://doi.org/10.1016/j.rasd.2013.07.020

Mandelli, V., Landi, I., Ceccarelli, S. B., Molteni, M., Nobile, M., D'Ausilio, A., Fadiga, L., Crippa, A., & Lombardo, M. V. (2024). Enhanced motor noise in an autism subtype with poor motor skills. *Molecular Autism*, *15*(1), Article 36. https://doi.org/10.1186/s13229-024-00618-0

Matheis, M., Matson, J. L., Burns, C. O., Jiang, X., Peters, W. J., Moore, M., de Back, K. A., & Estabillo, J. (2017). Factors related to parental age of first concern in toddlers with autism spectrum disorder. *Developmental Neurorehabilitation*, *20*(4), 228–235. https://doi.org/10.1080/17518423.2016.1211186

Memari, A. H., Ghanouni, P., Shayestehfar, M., & Ghaheri, B. (2014). Postural control impairments in individuals with autism spectrum disorder: A critical review of current literature. *Asian Journal of Sports Medicine*, *5*(3), Article e22963. https://doi.org/10.5812/asjsm.22963

Miller, L. E., Perkins, K. A., Dai, Y. G., & Fein, D. A. (2017). Comparison of parent report and direct assessment of child skills in toddlers. *Research in Autism Spectrum Disorders*, *41–42*, 57–65. https://doi.org/10.1016/j.rasd.2017.08.002

Mullen, E. M. (1995). *Mullen Scales of Early Learning*. American Guidance Service.

Ohara, R., Kanejima, Y., Kitamura, M., & Izawa, K. P. (2019). Association between social skills and motor skills in individuals with autism spectrum disorder: A systematic review. *European Journal of Investigation in Health, Psychology and Education*, *10*(1), 276–296. https://doi.org/10.3390/ejihpe10010022

Pokoski, O. M., Furnier, S. M., Gangnon, R. E., Howerton, E. M., Kirby, A. V., Protho, T., Schweizer, M. L., Travers, B. G., & Durkin, M. S. (2025). Prevalence of motor milestone delays in autistic children. *JAMA Pediatrics*, *179*, 759–764. https://doi.org/10.1001/jamapediatrics.2025.0216

Posar, A., & Visconti, P. (2022). Early motor signs in autism spectrum disorder. *Children*, *9*(2), Article 294. https://doi.org/10.3390/children9020294

Reynolds, J. E., Whitehouse, A. J. O., Alvares, G. A., Waddington, H., Macaskill, E., & Licari, M. K. (2022). Characterising the early presentation of motor difficulties in autistic children. *Journal of Autism and Developmental Disorders*, *52*(11), 4739–4749. https://doi.org/10.1007/s10803-021-05333-w

Rutter, M., Bailey, A., & Lord, C. (2003). *The Social Communication Questionnaire*. Western Psychological Services.

Ryberg, R., Wiggins, L., Moore, K. A., Daily, S., Piña, G., & Klin, A. (2022). Measuring state-level infant and toddler well-being in the United States: Gaps in data lead to gaps in understanding. *Child Indicators Research*, *15*(3), 1063–1102. https://doi.org/10.1007/s12187-021-09902-4

Sacrey, L. A., Zwaigenbaum, L., Bryson, S., Brian, J., Smith, I. M., Roberts, W., Szatmari, P., Roncadin, C., Garon, N., Novak, C., Vaillancourt, T., McCormick, T., MacKinnon, B., Jilderda, S., & Armstrong, V. (2015). Can parents' concerns predict autism spectrum disorder? A prospective study of high-risk siblings from 6 to 36 months of age. *Journal of the American Academy of Child & Adolescent Psychiatry*, *54*(6), 470–478. https://doi.org/10.1016/j.jaac.2015.03.014

Sansi, A., Nalbant, S., & Ozer, D. (2021). Effects of an inclusive physical activity program on the motor skills, social skills and attitudes of students with and without autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *51*(7), 2254–2270. https://doi.org/10.1007/s10803-020-04693-z

Schendel, D. E., Diguiseppi, C., Croen, L. A., Fallin, M. D., Reed, P. L., Schieve, L. A., Wiggins, L. D., Daniels, J., Grether, J., Levy, S. E., Miller, L., Newschaffer, C., Pinto-Martin, J., Robinson, C., Windham, G. C., Alexander, A., Aylsworth, A. S., Bernal, P., Bonner, J. D., . . .Yeargin-Allsopp, M. (2012). The Study to Explore Early Development (SEED): A multisite epidemiologic study of autism by the Centers for Autism and Developmental Disabilities Research and Epidemiology (CADDRE) network. *Journal of Autism and Developmental Disorders*, *42*(10), 2121–2140. https://doi.org/10.1007/s10803-012-1461-8

Shenouda, J., Barrett, E., Davidow, A. L., Sidwell, K., Halperin, W., Silenzio, V. M. B., & Zahorodny, W. (2022). Disparities in early intervention program participation by children with autism spectrum disorder in a US metropolitan area, 2006 to 2016. *JAMA Pediatrics*, *176*(9), 906–914. https://doi.org/10.1001/jamapediatrics.2022.2366

Smith, K. A., Gehricke, J. G., Iadarola, S., Wolfe, A., & Kuhlthau, K. A. (2020). Disparities in service use among children with autism: A systematic review. *Pediatrics*, *145*(Suppl. 1), S35–S46. https://doi.org/10.1542/peds.2019-1895G

Sparrow, S. S., Cicchetti, D. V., & Balla, D. A. (2005). *Vineland Adaptive Behavior Scales, Second Edition: Survey forms manual*. Pearson Assessments.

Teh, S. E., Vo, L. T. V., & Bal, V. H. (2024). Factors that influence the daily living skills of autistic adults: The importance of opportunity. *Journal of Autism and Developmental Disorders*, *54*(12), 4432–4443. https://doi.org/10.1007/s10803-023-06154-9

Travers, B. G., Bigler, E. D., Duffield, T. C., Prigge, M. D. B., Froehlich, A. L., Lange, N., Alexander, A. L., & Lainhart, J. E. (2017). Longitudinal development of manual motor ability in autism spectrum disorder from childhood to mid-adulthood relates to adaptive daily living skills. *Developmental Science*, *20*(4), Article e12401. https://doi.org/10.1111/desc.12401

Travers, B. G., Powell, P. S., Klinger, L. G., & Klinger, M. R. (2013). Motor difficulties in autism spectrum disorder: Linking symptom severity and postural stability. *Journal of Autism and Developmental Disorders*, *43*(7), 1568–1583. https://doi.org/10.1007/s10803-012-1702-x

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gotzsche, P. C., Vandenbroucke, J. P., & Initiative, S. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *The Lancet*, *370*(9596), 1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X

Wang, L. A. L., Petrulla, V., Zampella, C. J., Waller, R., & Schultz, R. T. (2022). Gross motor impairment and its relation to social skills in autism spectrum disorder: A systematic review and two meta-analyses. *Psychological Bulletin*, *148*(3–4), 273–300. https://doi.org/10.1037/bul0000358

West, K. L. (2019). Infant motor development in autism spectrum disorder: A synthesis and meta-analysis. *Child Development*, *90*(6), 2053–2070. https://doi.org/10.1111/cdev.13086

Wiggins, L. D., Bakeman, R., Adamson, L. B., & Robins, D. L. (2007). The utility of the Social Communication Questionnaire in screening for autism in children referred for early intervention. *Focus on Autism and Other Developmental Disabilities*, *22*(1), 33–38. https://doi.org/10.1177/10883576070220010401

Wiggins, L. D., Reynolds, A., Rice, C. E., Moody, E. J., Bernal, P., Blaskey, L., Rosenberg, S. A., Lee, L.-C., & Levy, S. E. (2015). Using standardized diagnostic instruments to classify children with autism in the study to explore early development. *Journal of Autism and Developmental Disorders*, *45*(5), 1271–1280. https://doi.org/10.1007/s10803-014-2287-3

Wing, L. (1997). The autistic spectrum. *The Lancet*, *350*(9093), 1761–1766. https://doi.org/10.1016/s0140-6736(97)09218-0

Zubler, J. M., Wiggins, L. D., Macias, M. M., Whitaker, T. M., Shaw, J. S., Squires, J. K., Pajek, J. A., Wolf, R. B., Slaughter, K. S., Broughton, A. S., Gerndt, K. L., Mlodoch, B. J., & Lipkin, P. H. (2022). Evidence-informed milestones for developmental surveillance tools. *Pediatrics*, *149*(3), e2021052138. https://doi.org/10.1542/peds.2021-052138