Advances in Neurodevelopmental Disorders (2024) 8:235–241
https://doi.org/10.1007/s41252-023-00340-7

ORIGINAL PAPER

Associations Across Developmental Domains in Autistic Toddlers

Jamie M. Holloway[1] · Farina A. Klocksieben[2] · Emily Shaffer-Hudkins[2]

Accepted: 7 June 2023 / Published online: 17 June 2023

Abstract

Objectives While diagnostic criteria for autism focus on social communication and behavioral deficits, many autistic children also demonstrate difficulties with motor skills. The nature of connection between these motor difficulties and other areas of development remains largely unknown, especially in young children. This preliminary study explored the relationships between motor skills and social function in autistic toddlers, with consideration to the role of cognitive function.

Methods Nineteen autistic toddlers between the ages of 18 and 42 months participated. Motor, cognitive, and personal–social skills were assessed using standardized measures.

Results Seventy-nine percent of children demonstrated below average total motor scores (< 1 SD below test mean). Motor skills in autistic toddlers were positively associated with social skills; however, this relationship may be impacted by cognitive skills. Visual–motor integration, grasping, and ball skills specifically were also positively associated with social function.

Conclusions These preliminary findings suggest the relevance of motor skill development in social functioning among young autistic children and help to inform future research examining interactions across developmental domains in this population.

Keywords Motor development · Autism · Infants and toddlers · Social development · Cognitive development

Diagnostic features of autism include impairments in social communication and interaction and atypical patterns of repetitive or restrictive behaviors; however, many autistic individuals also demonstrate motor impairments such as decreased postural control and coordination (Bhat et al., 2011). As many as 87% of autistic children demonstrate fine and gross motor delays (Bhat, 2020). Autistic children have greater difficulty maintaining body position when perturbed and sway more in different stance positions than typically developing peers (Lim et al., 2017). Learning new movements is often slower and more variable than typically developing peers (Isenhower et al., 2012; Kaur et al., 2018). When walking, autistic individuals compensate for the difficulties in the movement system by using a wider base of support and modified range of motion in order to maintain upright control (Kindregan et al., 2015). Approximately 31% of autistic individuals also have intellectual disability, which may explain, in part, the presence of motor difficulties in this population given the known connection between these areas of functioning (Maenner et al., 2020). While presence of cognitive delay or impairment may impact motor development, studies that have controlled for cognition in older autistic children have found that these movement differences persist and cannot be explained by neurocognitive deficits alone (Kaur et al., 2018; Ramos-Sánchez et al., 2022).

Motor skills are an important component of overall development. During early childhood, movement experiences provide opportunities for interactions with the environment and may facilitate many facets of early childhood developmental skills (Campos et al., 2000; Holloway & Long, 2019). Due to the interrelatedness of each area of developmental skills, children naturally engage in holistic learning whereby one domain influences and is influenced by development in other domains (Shonkoff & Phillips, 2000). Given that social skills are one of the developmental domains most closely aligned with the core features of autism, the current study included a focus on motor and social functioning. Previous studies have demonstrated links between these areas of development, indicating that autistic children who have lower motor scores also have lower scores in social function and participation in social interaction activities (Holloway et al., 2018, 2021; Mody et al., 2017; Pusponegoro et al., 2016).

✉ Jamie M. Holloway
jhollow1@graceland.edu

[1] Graceland University, Independence, MO, USA

[2] University of South Florida, Tampa, FL, USA

In autistic children 5–15 years of age, the relative risk of motor impairment is greater with increasing risk of deficits in social communication, cognitive, or overall functional abilities (Bhat, 2021). Specific components of movement, such as motor coordination, have also been linked to socio-adaptive function in school-aged autistic children (Kostrubiec et al., 2018). While studies have indicated there is an association between developmental domains across all ages, little empirical examination exists specifically for very young autistic children.

Early identification and intervention are important for optimal outcomes for autistic children (Sanchack & Thomas, 2016). Understanding the relationship between motor development and social function in very young autistic children is important in order to tailor intervention and optimize learning opportunities at this critical time in development; however, there is a paucity of research investigating these relationships in autistic toddlers. Pusponegoro et al. (2016) reported significantly lower motor scores at 1–2 years and 3 years of age for children in the autism group compared to those who were typically developing; however, they only reported relationships between motor and social skills for the study group as a whole (18 months–6 years) rather than by age. MacDonald et al. (2014) found significant relationships between motor skills and autism severity in toddlers, but the specific link between motor and social skills was not explored. Findings from a systematic review of 21 studies investigating the relationship between gross motor and social skills indicate these areas are related; however, only two studies included in the review focused on autistic children under the age of 4 (Wang et al., 2022). The authors also noted the studies with younger children were often retrospective in nature and recommended prospective designs for future research. Given the importance of early diagnosis and intervention for autistic children, continued exploration of this relationship in toddlers is essential to understand how this relationship changes over time.

The purpose of this study was to prospectively examine the relationship between motor skills and social interaction in autistic toddlers, independently and with respect to cognitive function. The study also aimed to determine the frequency of motor delay in autistic toddlers and identify specific components of motor skills that were related to social function in this population. We hypothesized that gross and fine motor skills in the sample would be delayed compared to typically developing peers, with a positive correlation between motor and social function. We also hypothesized that specific components of motor skills such as balance and ball handling abilities would be positively associated with social function in autistic toddlers, based on previous work with preschoolers.

Methods

Participants

Autistic children aged 18–42 months were recruited from local clinics, early intervention service providers, and organizations in the southeastern United States that serve this population. Children were included if they met the following criteria: (1) previously diagnosed with autism by an appropriate licensed healthcare professional, (2) 18–42 months of age, (3) able to follow administrative guidelines for each developmental assessment, and (4) without uncorrected vision or hearing impairments. Diagnosis of autism was confirmed by report from the physician or psychologist who gave the diagnosis. Ability to follow administrative guidelines for each developmental assessment included responses to test item administration using visual demonstration, hand over hand assistance, and/or verbal directions and was determined by a question at initial screening regarding participation in previous developmental testing. Children were excluded from the study if they had a co-morbid diagnosis known to impact motor ability, such as spina bifida or cerebral palsy. After an extended period of 26 months of ongoing recruitment that was also impacted by the COVID-19 pandemic, a final sample size of 19 was reached for subsequent data analyses.

Nineteen autistic toddlers and their primary parent or caregiver participated in this study. Participant characteristics are summarized in Table 1. The age of participants ranged from 21 to 41 months ($M = 33$ months and SD = 5.4). Diagnosis of autism was confirmed by physician report. The most common services received were speech

Table 1 Participant demographics

	Number (%), $N = 19$
Race	
White	11(57.9%)
African American	3 (15.8%)
Asian	1 (5.3%
Other/more than 1 race	4 (21.1%)
Ethnicity	
Hispanic	6 (31.6%)
Non-Hispanic	13 (68.4%
Gender	
Male	14 (73.7%)
Female	5 (26.3%)
ASD severity level	
Level 1	3 (15.8%)
Level 2	5 (26.3%)
Level 3	2 (10.5%)
Not reported	9 (47.4%)

therapy (31.82%), occupational therapy (22.37%), developmental specialist (18.18%), and applied behavior analysis (18.18%). One participant was receiving physical therapy services at the time of the study visit and an additional 2 participants reported receiving physical therapy in the past. Three children (15.79%) attended a private childcare setting, two (10.53%) attended a special education preschool class through the public schools, two (10.53%) attended a private ABA-based classroom, and the other twelve (63.16%) were home with a parent during the day.

Most participants obtained developmental scores in the significantly delayed range. Cognitive quotients ranged from 57 to 109 ($M = 73.6$ and SD = 13.4). Only 4/19 (21%) children scored in the average range between 85 and 115. BDI-2 Personal Social Quotients ranged from 58 to 90 ($M = 68.4$ and SD = 8.7). Only 1 (5%) child in the sample scored in the average range between 85 and 115.

Procedures

All assessments were completed during a single 2-h visit to the testing site at a university-based research lab by the participant and his or her caregiver. The Peabody Developmental Motor Scales 2nd edition (PDMS-2) and Battelle Developmental Inventory 2nd edition (BDI-2) Cognitive subtest were administered by the same physical therapist with formal training in both measures and over 15 years of pediatric clinical experience. The parent/caregiver accompanying the child to the visit filled out a demographics form and participated in the interview for the personal–social subtest of the BDI-2. A school psychologist and doctoral students in school psychology with training in the assessments also assisted with administration as needed. Children were given breaks as needed through the study visit. Parental consent was obtained prior to beginning the study. Written assent was waived due to the age of participants; however, agreement to participate in research tasks was obtained through verbal response from the child or observation of behavioral response. Families were compensated $50 as an incentive to participate.

Measures

Motor Skills

The PDMS-2 was used to measure fine and gross motor ability (Folio & Fewell, 2000). The gross motor subscales include measures of stationary, locomotion, and object manipulation (ball) skills. The fine motor subscales include measures of visual–motor integration and grasping skills. Administration of the PDMS-2 takes 45–60 min. The PDMS-2 is a valid measure of motor skill function in children from birth to 6 years of age and is widely used by physical and occupational therapists to measure fine and gross motor ability. While it has not been specifically validated in autistic children and toddlers, it has been used successfully in prior research with this population (Bremer et al., 2015; Holloway et al., 2018, 2019; Provost et al., 2007a, 2007b; Provost et al., 2007a, 2007b). Scoring of the PDMS-2 generates a raw score for each subtest (fine, gross, and total motor quotients) and individual subtest scaled scores.

Cognitive and Social Skills

The BDI-2 was used to measure cognitive and social development (Newborg, 2016). The BDI-2 is a standardized assessment tool that examines a child's development in adaptive, cognitive, language, motor, and personal–social areas. The BDI-2 is used with children from birth to 8 years old. For this study, the BDI-2 cognitive and personal–social domains were administered to assess cognitive and social function, respectively. Both of these domains are comprised of 3 subdomains that span numerous aspects of these skill sets and take 20–30 min each to administer. The BDI-2 is a valid measure for autistic children and toddlers and scores on the assessment are impacted by severity of autism symptoms (Goldin et al., 2014).

Data Analyses

Participant demographics were summarized using mean and standard deviation for continuous variables and percentages for categorical variables. The Shapiro–Wilk test was used to determine if the PDMS-2 subtests (stationary, locomotion, object manipulation, grasping, and visual–motor integration) and BDI-2 personal-social quotient (SOC) were normally distributed. They were not normally distributed; therefore, Spearman's correlation coefficients were used to assess the relationship between PDMS-2 subtests and BDI-2 personal-social quotient (SOC). Correlation coefficients range from 0 indicating no association to − 1 and + 1 indicating a perfect monotonic relationship.

Univariable linear regression models were fitted to examine the unadjusted association between motor skills, as measured by total motor quotient (TMQ) and social function, as measured by SOC. If a significant association was found, we subsequently fitted multivariable linear regression models adjusting for gender and cognitive skills, separately.

All statistical analyses were performed using IBM SPSS version 26. Power calculations were performed using PASS (Power Analysis and Sample Size Software, 2020 version). Statistical significance was set at 5%.

Results

Frequency of Motor Delay

Table 2 provides a summary of subtest and overall quotient scores from the PDMS-2. Subtest scores are presented as scale scores ($M = 10$ and SD = 3). Quotients are presented as standard scores ($M = 100$ and SD = 15). PDMS-2 total motor quotient (TMQ) scores ranged from 66 to 98 ($M = 77.7$ and SD = 9.3). The data showed that 15/19 children (79%) demonstrated below average total motor scores (< 1 SD below test mean), with 12/19 (63%) indicating a gross motor delay and 14/19 (74%) indicating a fine motor delay.

Motor and Social Relationships

Table 3 shows Spearman's correlation coefficients for PDMS-2 subtests and SOC. A statistically significant association was found between SOC and object manipulation ($r_s = 0.52$, $p = 0.02$), grasping ($r_s = 0.68$, $p = 0.001$), and visual–motor integration ($r_s = 0.69$, $p = 0.001$). There was also a statistically significant relationship between motor skills (TMQ) and social function ($\beta = 0.61$, 95% CI (0.26, 0.97), $p = 0.002$). The relationship between social function and motor skills remained significant when adjusting for gender ($\beta = 0.67$, 95% CI (0.22, 1.12), $p = 0.006$). However, when adjusting for cognitive skills, the relationship between social function and motor skills was no longer statistically significant ($\beta = 0.19$, 95% CI (−0.29, 0.68), $p = 0.415$). A sample size of 19 achieves 71% power to detect a slope of 0.61 under the alternative hypothesis, with a significance level of 0.05.

Table 2 Mean performance on Peabody Developmental Motor Scales ($n = 19$)

	Mean (SD)	Range
Stationary	7.8 (1.3)	6–10
Locomotion	6.3 (2.2)	3–11
Object manipulation	6.8 (2.3)	3–11
Gross motor quotient	80.4 (9.4)	66–102
Grasping	7.4 (1.8)	3–11
Visual–motor integration	5.5 (1.7)	4–11
Fine motor quotient	78.7 (9.4)	61–100
Total motor quotient	77.7 (9.3)	66–98

Discussion

This preliminary study demonstrated that autistic toddlers may have a high frequency of fine, gross, and total motor delay, which is consistent with the growing body of literature to support a high prevalence of fine and gross motor delay in this population (Bhat, 2020; Provost et al., 2007a, 2007b; Provost et al., 2007a, 2007b). Our study also suggests that higher motor skills may be associated with higher social function. Specific components of motor skills such as object manipulation (throwing, catching, and kicking a ball) and visual–motor integration also showed moderate to strong relationships with social skills in our sample. These preliminary findings in autistic toddlers are consistent with similar research in autistic preschoolers and older autistic children (Hedgecock et al., 2018; Holloway et al., 2018; Mody et al., 2017; Pusponegoro et al., 2016). The current study provides a preliminary contribution to this body of literature by examining these relationships prospectively, very early in development, and among a sample with a relatively recent autism diagnosis; however, findings should be viewed through a lens of caution due to the small sample size.

In our study, we also found that the overall motor–social relationship in toddlers may be impacted by cognitive skills, which may be explained by the natural tendency for holistic learning and the interdependence between developmental domains commonly reported in empirical studies of young children's development (Holloway & Long, 2019; Shonkoff & Phillips, 2000). While these findings are consistent with research in toddlers with other intellectual and developmental disabilities (Houwen et al., 2016), previous work on

Table 3 Spearman's correlations between PDMS-2 Motor Subscales and BDI-2 Personal-Social Quotients

	Stationary	Locomotion	Object manipulation	Grasping	Visual–motor integration	Personal–social
Stationary	1	0.183	0.290	0.401	0.419	0.323
Locomotion		1	0.353	0.285	0.443	0.167
Object manipulation			1	0.535*	0.583**	0.523*
Grasping				1	0.684**	0.679**
Visual–motor integration					1	0.690**
Personal–social						1

*$p < 0.05$

**$p < 0.01$

motor and social skills in autistic children has not consistently examined the role of cognitive functioning in the relationship, especially in toddlers. While cognitive ability may not fully explain the presence of motor impairment in this population, relationships between cognitive and motor skills have been shown in autistic children throughout childhood (Licari et al., 2020; Ramos-Sánchez et al., 2022).

The method of assessment of the developmental constructs in this study provides key information for understanding and interpreting findings. Cognitive skills in toddlers are comprised of attention and focus abilities (both to verbal and visual input), comprehension and processing of directions, and fine motor performance, as well as other factors. Thus, there is significant overlap across developmental domains and items that have been standardized to primarily examine one aspect of development require integration of other developmental skills. Structured BDI-2 cognitive subtest items require social awareness, attention to others' words and actions, and comprehension of language, in addition to problem solving skills, for successful completion of tasks. This may explain the potential impact of cognitive function to the relationship between motor and social skills in young autistic children.

Limitations and Future Research

The prospective nature of the study and requirements for a diagnosis of autism for eligibility contributed to the very small sample size, which was a limitation. Additionally, the small sample size made more robust exploration of the role of cognitive skills in this overall relationship difficult and results should be interpreted with caution. Likewise, children were only eligible to participate if they had been previously diagnosed with autism. Given the potential for delays recognizing symptoms and accessing evaluation services across different cultural and socioeconomic populations, it is possible the sample reflected only children from more affluent families with more resources, which limits generalizability. An additional limitation of the current study is the possibility of bias. The tests were administered and scored by the authors of the paper who were aware of the purpose of the study. To minimize this bias, tests and questionnaires were not scored until after the study visit was completed.

Despite growing evidence of motor difficulties in autistic children, the role that motor skill deficits play in this disorder remains unknown. Motor delay impacts many autistic children. A best practice for early intervention with young children is a simultaneous focus on multiple developmental domains through routine-based and play-based strategies (Agazzi et al., 2020); thus, understanding the relationship between motor difficulties and other areas of development may help inform future evaluation and intervention recommendations for this population.

Future research should continue to explore relationships and interactions between developmental domains in autistic individuals. This information will help researchers and clinicians better understand how to support autistic individuals in their daily lives. We recommend that future studies use a comprehensive approach by gathering information from all developmental domains to better understand these interactions. In this study, the relationship between motor and social skills became insignificant when cognitive was added as a variable; however, this finding should be interpreted with caution due to the small sample size. An additional consideration is the impact of communication. In our study, we did not assess communication; thus, we do not know how communication ties into the bigger picture. Future research with larger sample sizes and comprehensive assessments is needed to understand these relationships better.

Also, while exploration of these questions is important in all autistic individuals, the literature is especially lacking in very young autistic children. Future research should prospectively investigate these relationships at younger ages; however, researchers should also consider the difficulties in conducting research with children recently diagnosed. Recruitment for this study was extremely difficult and, as a result, our sample size was small. It is possible that families may not be ready to participate in research after recently receiving a diagnosis. Thus, findings from this study are exploratory and should be evaluated further. In future research with autistic toddlers, we recommend partnering with evaluation teams to enroll children and complete data collection during the diagnostic process in order to obtain a larger sample size. Additional insight may also be gleaned by examining these developmental relationships in children identified as showing signs of autism but who may have not yet had a confirmatory diagnosis. Given that best practice for pediatric healthcare and early intervention suggest autism screening at routine intervals in toddlers (i.e., at least 18 and 24 months), this would also provide opportunities for a much larger potential sample size.

In order to generalize results to the population, future research should report information regarding the severity of symptoms of autism using standard language from the DSM-5. In this study, diagnosis of autism was confirmed by obtaining a report from the healthcare professional who provided the diagnosis. Many of the reports did not utilize the DSM-5 levels of severity, making it difficult to analyze this variable among the sample. More consistency with specifying levels among the professionals assessing and diagnosing autism is needed to accurately identify severity of the individual needs and appropriate interventions. By doing so, this information can also then be obtained more readily in future studies. However, it is important to note that recent research has demonstrated changes in autism severity from early to middle childhood, with as many as 30% of autistic

3-year-olds having less severe symptoms at age 6 (Waizbard-Bartov et al., 2021). Thus, relationships between developmental skills and autism severity may best be interpreted at one time point rather than providing long-term implications.

Acknowledgements We would like to thank the graduate student assistants who helped with data collection and the children and parents who participated in the study.

Author contribution JH conceptualized and designed the study and acquired funding. JH and ES collected data and wrote the manuscript. FK analyzed data and reviewed the manuscript. All authors approved the final version of the manuscript for submission.

Funding This study was funded by the Florida Physical Therapy Association Linda Crane Research Award.

Data Availability All data are available at the Open Science Framework (https://osf.io/wcb47/).

Declarations

Ethical Approval This study was conducted according to the criteria set by the Declaration of Helsinki and was approved by the University of South Florida Institutional Review Board.

Informed Consent Informed consent/assent was obtained from each participant following procedures approved by the University of South Florida Institutional Review Board.

Conflict of Interest The authors declare no competing interests.

References

Agazzi, H., Shaffer-Hudkins, E. J., Armstrong, K. H., & Hayford, H. (2020). *Promoting positive behavioral outcomes for infants and toddlers* (pp. 21–33). Springer.

Bhat, A. N. (2020). Is motor impairment in autism spectrum disorder distinct from developmental coordination disorder? A report from the SPARK study. *Physical Therapy, 100*(4), 633–644. https://doi.org/10.1093/ptj/pzz190

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., Landa, R. J., & Galloway, J. C. (2011). Current perspectives on motor functioning in infants, children, and adults with autism spectrum disorders. *Physical Therapy, 91*(7), 1116–1129. https://doi.org/10.2522/ptj.20100294

Bremer, E., Balogh, R., & Lloyd, M. (2015). Effectiveness of a fundamental motor skill intervention for 4-year-old children with autism spectrum disorder: A pilot study. *Autism, 19*(8), 980–991. https://doi.org/10.1177/1362361314557548

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy, 1*(2), 149–219. https://doi.org/10.1207/S15327078IN0102_1

Folio, M. R., & Fewell, R. R. (2000). *Peabody Developmental Motor Scales* (2nd ed.). Pro-Ed Inc.

Goldin, R. L., Matson, J. L., Beighley, J. S., & Jang, J. (2014). Autism spectrum disorder severity as a predictor of Battelle Developmental Inventory second edition BDI 2 scores in toddlers. *Developmental Neurorehabilitation. 17*(1):39–43. https://doi.org/10.3109/17518423.2013.839585

Hedgecock, J. B., Dannemiller, L. A., Shui, A. M., Rapport, M. J., & Katz, T. (2018). Associations of gross motor delay, behavior, and quality of life in young children with autism spectrum disorder. *Physical Therapy, 98*(4), 251–259. https://doi.org/10.1093/ptj/pzy006

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

Holloway, J. M., Long, T. M., & Biasini, F. (2018). Relationships between gross motor skills and social function in young boys with autism spectrum disorder. *Pediatric Physical Therapy, 30*(3), 184–190. https://doi.org/10.1097/pep.0000000000000505

Holloway, J. M., Long, T., & Biasini, F. (2019). Concurrent validity of two standardized measures of gross motor function in young children with autism spectrum disorder. *Physical & Occupational Therapy in Pediatrics, 39*(2), 193–203. https://doi.org/10.1080/01942638.2018.1432006

Holloway, J. M., Long, T. M., & Biasini, F. J. (2021). The intersection of gross motor abilities and participation in children with autism spectrum disorder. *Infants & Young Children, 34*(3), 178–189. https://doi.org/10.1097/IYC.0000000000000192

Houwen, S., Visser, L., van der Putten, A., & Vlaskamp, C. (2016). The interrelationships between motor, cognitive, and language development in children with and without intellectual and developmental disabilities. *Research in Developmental Disabilities, 53–54*, 19–31. https://doi.org/10.1016/j.ridd.2016.01.012

Isenhower, R. W., Marsh, K. L., Richardson, M. J., Helt, M., Schmidt, R. C., & Fein, D. (2012). Rhythmic bimanual coordination is impaired in young children with autism spectrum disorder. *Research in Autism Spectrum Disorders, 6*(1), 25–31. https://doi.org/10.1016/j.rasd.2011.08.005

Kaur, M., Srinivasan, S. M., & Bhat, A. N. (2018). Comparing motor performance, praxis, coordination, and interpersonal synchrony between children with and without autism spectrum disorder (ASD). *Research in Developmental Disabilities, 72*, 79–95. https://doi.org/10.1016/j.ridd.2017.10.025

Kindregan, D., Gallagher, L., & Gormley, J. (2015). Gait deviations in children with autism spectrum disorders: A review. *Autism Research and Treatment*, *2015*, 741480. https://doi.org/10.1155/2015/741480

Kostrubiec, V., Huys, R., Jas, B., & Kruck, J. (2018). Age-dependent relationship between socio-adaptability and motor coordination in high functioning children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 48*(1), 209–224. https://doi.org/10.1007/s10803-017-3326-7

Licari, M. K., Alvares, G. A., Varcin, K., Evans, K. L., Cleary, D., Reid, S. L., Glasson, G. J., Bebbington, J. E., 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., Partridge, K., Girdler, S., & Morris, S. L. (2017). Standing postural control in individuals with autism spectrum disorder: Systematic review and meta-analysis. *Journal of Autism and Developmental Disorders, 47*(7), 2238–2253. https://doi.org/10.1007/s10803-017-3144-y

MacDonald, M., Lord, C., & Ulrich, D. A. (2014). Motor skills and calibrated autism severity in young children with autism spectrum disorder. *Adapted Physical Activity Quarterly, 31*(2), 95–105. https://doi.org/10.1123/apaq.2013-0068

Maenner, M. J., Shaw, K. A., Baio, J., Washington, A., Patrick, M., DiRienzo, M., Christensen, D. L., Wiggins, L. D., Pettygrove, S., Andrews, J. G., Lopez, M., Hudson, A., Baroud, T., Schwenk, Y., White, T., Rosenberg, C. R., Lee, L. C., Harrington, R. A., Huston, M., Hewitt, A., . . . Dietz, P. M. (2020). Prevalence of autism

spectrum disorder among children aged 8 years — Autism and developmental disabilities monitoring network, 11 Sites, United States, 2016. *Morbidity and mortality weekly report. Surveillance summaries (Washington, D.C.:2002)*, *69*(4), 1–12. https://doi.org/10.15585/mmwr.ss6904a1

Mody, M., Shui, A. M., Nowinkski, L. A., Golas, S. B., Ferrone, C., O'Rourke, J. A., & McDougle, C. J. (2017). Communication deficits and the motor system: Exploring patterns of associations in autism spectrum disorder. *Journal of Autism and Developmental Disorders, 47*(1), 155–162. https://doi.org/10.1007/s10803-016-2934-y

Newborg, J. (2016). *Battelle developmental inventory* (2nd ed.). Houghton Mifflin Harcourt.

PASS. (2020). Power Analysis and Sample Size Software (Version 2020). [Computer software]. https://www.ncss.com/software/pass

Provost, B., Heimerl, S., & Lopez, B. R. (2007a). Levels of gross and fine motor development in young children with autism spectrum disorders. *Physical & Occupational Therapy in Pediatrics, 27*(3), 21–36. https://doi.org/10.1080/J006v27n03_03

Provost, B., Lopez, B. R., & Heimerl, S. (2007b). A comparison of motor delays in young children: Autism spectrum disorder, developmental delay, and developmental concerns. *Journal of Autism and Developmental Disorders, 37*(2), 321–328. https://doi.org/10.1007/s10803-006-0170-6

Pusponegoro, H. D., Efar, P., Soedjatmiko, S., Firmansyah, A., Chen, H. J., & Hung, K. L. (2016). Gross motor profile and its association with socialization skills in children with autism spectrum disorders. *Pediatrics and Neonatology, 57*(6), 501–507. https://doi.org/10.1016/j.pedneo.2016.02.004

Ramos-Sánchez, C. P., Kortekaas, D., Van Biesen, D., Vancampfort, D., & Van Damme, T. (2022). The relationship between motor skills and intelligence in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 52*, 1189–1199. https://doi.org/10.1007/s10803-021-05022-8

Sanchack, K. E., & Thomas, C. A. (2016). Autism spectrum disorder: Primary care principles. *American Family Physician, 94*(12), 972–979.

Shonkoff, J. P., & Phillips, D. A. (Eds.). (2000). *From neurons to neighborhoods: The science of early childhood development*. National Academies Press (US).

Waizbard-Bartov, E., Ferrer, E., Young, G. S., Heath, B., Rogers, S., Wu Nordahl, C., Solomon, M., & Amaral, D. G. (2021). Trajectories of autism symptom severity change during early childhood. *Journal of Autism and Developmental Disorders, 51*, 227–242. https://doi.org/10.1007/s10803-020-04526-z

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