

SHORT REPORT

Motor skills predict adaptive behavior in autistic children and adolescents

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Abstract

It is well-documented that intelligence quotient (IQ) is a poor predictor of adaptive behavior scores in autism, with autistic children having lower adaptive behavior scores than would be predicted based on their IQ scores. Differences in motor skills may explain the variability in their adaptive behavior scores. The current study examined how motor skills might explain autistic individuals' low adaptive behavior scores and which individual components of IQ (i.e., verbal comprehension and perceptual reasoning) and motor skills (i.e., manual dexterity, aiming and catching, and balance) may drive this effect. We examined the associations between IQ, motor skills, calibrated severity, and adaptive behavior scores in 45 autistic children and adolescents. Using a *t*-test, we found a significant difference ($p < 0.001$) between full-scale IQ and adaptive behavior scores, indicating that our participants' adaptive behavior scores were lower than would be expected given their full-scale IQ. Using a linear regression, we investigated whether motor skills predicted adaptive behavior in autistic children and adolescents and found that motor skills scores were associated with adaptive behavior scores ($p = 0.022$). To further investigate these associations, we used another linear regression to examine how individual components of IQ and motor skills predicted adaptive behavior scores in autistic children and adolescents. Our results indicated that manual dexterity scores were associated with adaptive behavior scores ($p = 0.036$). These findings clearly illustrate the need for further understanding of autistic individuals' difficulties with adaptive behavior and the potential role of motor skill difficulties that may underlie these difficulties.

Lay Summary

Autistic children have lower adaptive behavior scores (e.g., daily living skills, social skills, communication) than intelligence scores (e.g., verbal and perceptual skills) along with difficulties with motor skills. Motor skills may explain the gap between adaptive behavior and intelligence. We found motor skills were associated with adaptive behavior in autistic children and adolescents. In particular, hand coordination was associated with adaptive behavior. We need to better understand how autistic individuals' motor skills impact their adaptive behavior to provide effective supports.

KEYWORDS

adaptive behavior, autism spectrum disorder, intelligence, motor skills, movement disorder

The study described in this manuscript was conducted while NEF and HLM were affiliated with the University of North Texas Health Science Center. All authors are currently affiliated with the University of Michigan.

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INTRODUCTION

Adaptive behavior skills are vital for independent living. Difficulties with adaptive behaviors in domains such as self-care (e.g., brushing teeth, dressing), self-feeding (e.g., eating with utensils), and play (e.g., drawing, manipulating puzzle pieces) can negatively impact quality of life and limit participation in activities (Delgado-Lobete et al., 2021; Magalhães et al., 2011). In autism, it is well-documented that intelligence quotient (IQ) scores are poor predictors of adaptive behavior scores. Autistic children score lower on adaptive behavior assessments than would be predicted based on their scores on IQ assessments (Alvares et al., 2020; Duncan & Bishop, 2015; Kraper et al., 2017; Perry et al., 2009; Smith et al., 2012). Specifically, autistic children's IQ scores were not significantly related to their adaptive behavior scores, suggesting that using IQ scores to estimate functional ability is unproductive and, in some cases, harmful (Alvares et al., 2020). Overestimating autistic children's adaptive behavior skills based on their IQ scores may cause caregivers and service providers to underestimate the supports that autistic children need (Alvares et al., 2020). In turn, this lack of support may lead to increased anxiety and depression (Zukerman et al., 2021).

Motor skills have been found to be related to cognitive, language, and social development. In infancy, motor skills are related to the development of language (Libertus & Violi, 2016; West et al., 2019), joint attention (Yu & Smith, 2017), and cognition (Soska et al., 2010). In childhood, motor skills are related to school performance (Cameron et al., 2016), social communication (Bhat, 2021; Dziuk et al., 2007), cognition (Bhat, 2021), and imitation (Lidstone & Mostofsky, 2021). Given these relations between motor skills and a wide range of domains throughout development, motor skills may better predict differences in adaptive behavior than IQ scores in autism.

Motor difficulties are related to adaptive behavior in related neurodevelopmental disorders, such as Developmental Coordination Disorder (Delgado-Lobete et al., 2021; Magalhães et al., 2011), and there is strong evidence that autistic children have similar clinically-significant motor difficulties (Bhat, 2021; Green et al., 2009; Miller et al., 2021). Green et al. (2009) reported that 79%–89% of autistic children had definitive or borderline motor difficulties, respectively. Bhat (2021) reported that 86.9%–88% of autistic children are at-risk for motor difficulties according to caregivers' survey responses, with the risk of motor difficulties being 22 times greater than that of the general population. Further, Miller et al. (2021) reported that more than 90% of autistic children met the criteria for clinically significant motor difficulties on the Movement Assessment Battery for Children, Second Edition (MABC-2; Henderson et al., 2007), the gold-standard standardized assessment of motor ability. Examining specific motor skills,

researchers have measured differences in quiet standing (Lim et al., 2017), leaning (Miller et al., 2019; Wang et al., 2016), stepping (Bojanek et al., 2020), reaching (Glazebrook et al., 2006), grasping (Carment et al., 2020; Mosconi et al., 2015; Travers et al., 2017), catching (Chen et al., 2019), and tool use (Mostofsky et al., 2006). These motor difficulties are implicated in social, cognitive, and adaptive function and in turn, have implications for autistic children's quality of life and mental health (Tampain & Miller, 2020).

For autistic individuals, fine motor skills may impede the development of adaptive behavior. Travers et al. (2017) demonstrated that fine motor skill difficulties constrain adaptive behavior and lead to decreased participation in activities of daily living over time in autistic children and adolescents. In a related study of children with developmental coordination disorder, fine motor skills fully mediated the association between individual constraints and delayed learning on activities of daily living, highlighting the association between fine motor skills and adaptive behavior (Delgado-Lobete et al., 2021). Importantly, fine motor skill difficulties in autism have been shown to increase with time, reducing the likelihood of independent living in adulthood (Travers et al., 2017). Fine motor skill difficulties that reduce an individual's capacity to engage in activities of daily living may also limit access to developmental opportunities in other domains (e.g., social, communication, language; Adolph & Hoch, 2019; Houwen et al., 2016).

Given the poor predictive ability of IQ scores for autistic individuals' adaptive behavior and their documented motor difficulties, this study aimed to determine (1) how measures of motor skills might explain autistic individuals' low adaptive behavior scores and (2) which individual components of IQ (i.e., verbal comprehension and perceptual reasoning) and motor skills (i.e., manual dexterity, aiming and catching, and balance) may drive this effect. We hypothesized that motor skills would be related to autistic individuals' adaptive behavior scores, and that manual dexterity and balance, in particular, would drive this effect.

METHODS

Participants

We assessed 45 autistic children and adolescents (Male = 38, Female = 7). Participants were included in the study if the participant's guardian reported they had a prior diagnosis of autism spectrum disorder or Asperger's syndrome from an educational or healthcare professional according to DSM-IV or DSM-V criteria, and a research-reliable member of the study team administered the ADOS-2 (Lord et al., 2012) to confirm that the participant's scores fell within the cutoff for a classification of autism. Children and adolescents ages 5 through

17 years were recruited from the community via study flyers and word of mouth.

Potential participants with a current or prior diagnosis of a genetic or neurological disorder (not including autism), brain injury, meningitis, structural brain abnormality, motion sickness, neurofibromatosis, seizure disorder, head injury or concussion with loss of consciousness, psychiatric diagnosis (not including anxiety or depression), movement disorder (e.g., cerebral palsy), oculomotor disorder, or a full-scale IQ score of <70 on the WASI-II (Wechsler, 2011) were excluded from participation, as well as those who were currently taking benzodiazepines or antipsychotics.

Procedure

Participants were assessed using the ADOS-2 (Lord et al., 2012), MABC-2 (Henderson et al., 2007), and the WASI-II (Wechsler, 2011) by a trained member of the research team at an urban health science center during one to two sessions, depending on the participants' stamina and availability. Calibrated severity scores were calculated with the ADOS-2 (Hus & Lord, 2014; Lord et al., 2012). Standard scores for movement total and for the manual dexterity, aiming and catching, and balance subscales were calculated from the MABC-2 (Henderson et al., 2007). Standard scores for full-scale IQ and for the verbal comprehension, and perceptual reasoning subscales were calculated from the WASI-II. Participants' guardians reported the participants' adaptive behavior abilities on the communication, daily living skills, and socialization domains of the Vineland-3 (Sparrow, Cicchetti, & Balla, 2016). These three domains were used to calculate the Adaptive Behavior Composite standard scores. The standard scores of the WASI-II and Vineland-3 are normed to a normal distribution with a mean of 100 and a standard deviation of 15. See Table S1

for standard error of measurement and test–retest reliability statistics.

Data analysis

Data were analyzed using R (R Core Team, 2021). A paired *t*-test was used to compare the means of participants' standard scores on the WASI-II and Vineland-3. Exploratory Pearson's product–moment correlations were calculated to examine the relations between the standardized assessments scores and age. Linear regressions were used to predict participants' adaptive behavior composite scores from the other standardized assessment scores and age. For the linear regression models, model assumptions of linearity and homoscedasticity of the residuals were visually evaluated using residual plots, and the model assumption of normality of residuals was visually evaluated using Q-Q plots. Significance tests for linear regressions used sums of squares type III and alpha was $p < 0.05$.

RESULTS

Descriptive statistics

Descriptive statistics are presented in Table 1. We conducted exploratory correlational analyses to examine the relations between participants' age and each of the variables derived from the standardized assessments. These analyses resulted in two notable correlations between the MABC-2 and adaptive behavior (movement total, $r = 0.35$, $p = 0.017$; manual dexterity, $r = 0.32$, $p = 0.031$) indicating that movement total and manual dexterity scores are individually associated with adaptive behavior scores. The full correlation matrix is presented in Table 2.

TABLE 1 Descriptive statistics for participants' age and standardized assessment scores

Variable	Mean	SD	Median	Min	Max
Age (years)	12.30	3.48	12.44	5.18	17.80
VABS-3 adaptive behavior composite	78.49	12.59	79	48	110
MABC-2 movement total	4.22	2.56	5	1	10
MABC-2 manual dexterity	4.71	2.74	4	1	11
MABC-2 aiming and catching	5.22	2.95	5	1	10
MABC-2 balance	5.71	3.40	6	1	14
WASI-II full-scale IQ	103.87	16.53	105	70	138
WASI-II verbal comprehension	103.33	15.78	105	74	132
WASI-II perceptual reasoning	103.87	18.46	106	67	138
ADOS-2 calibrated severity	9.07	1.30	10	5	10

Note: All scores reported are standard scores. There was no significant difference in age between male and female participants (Welch $t_{8,64} = -0.87$, $p = 0.406$). Abbreviations: ADOS-2, Autism Diagnostic Observation Schedule (2nd edition); MABC-2, Movement Assessment Battery for Children (2nd edition); VABS-3, Vineland Adaptive Behavior Scales (3rd edition); WASI-II, Wechsler Abbreviated Scale of Intelligence (2nd edition).

TABLE 2 Exploratory Pearson correlation coefficients for participants' age and standardized assessment scores

Variable	1	2	3	4	5	6	7	8	9	10
1. Age	1.00	-0.41*	-0.14	-0.15	-0.29*	-0.05	-0.11	-0.08	-0.11	0.33*
2. VABS-3 adaptive behavior	-0.41*	1.00	0.35*	0.32*	0.22	0.21	0.16	0.15	0.08	0.01
3. MABC-2 movement total	-0.14	0.35*	1.00	0.85*	0.64*	0.80*	0.49*	0.27	0.53*	-0.25
4. MABC-2 manual dexterity	-0.15	0.32*	0.85*	1.00	0.51*	0.49*	0.59*	0.31*	0.67*	-0.21
5. MABC-2 aiming and catching	-0.29*	0.22	0.64*	0.51*	1.00	0.31*	0.32*	0.22	0.27	-0.45*
6. MABC-2 Balance	-0.05	0.21	0.80*	0.49*	0.31*	1.00	0.34*	0.20	0.36*	-0.13
7. WASI-II full-scale IQ	-0.11	0.16	0.49*	0.59*	0.32*	0.34*	1.00	0.85*	0.85*	-0.16
8. WASI-II verbal comprehension	-0.08	0.15	0.27	0.31*	0.22	0.20	0.85*	1.00	0.46*	-0.20
9. WASI-II perceptual reasoning	-0.11	0.08	0.53*	0.67*	0.27	0.36*	0.85*	0.46*	1.00	-0.07
10. ADOS-2 calibrated severity	0.33*	0.01	-0.25	-0.21	-0.45*	-0.13	-0.16	-0.20	-0.07	1.00

* $p < 0.05$. Correlation analyses were exploratory and p values were not adjusted for multiple comparisons.

Abbreviations: ADOS-2, Autism Diagnostic Observation Schedule (2nd edition); MABC-2, Movement Assessment Battery for Children (2nd edition); VABS-3, Vineland Adaptive Behavior Scales (3rd edition); WASI-II, Weschler Abbreviated Scale of Intelligence (2nd edition).

Difference between IQ and adaptive behavior scores

We used a paired-samples t -test comparing participants' full-scale IQ and adaptive behavior scores to determine whether our data set replicated the previously found difference between these scores in autistic children and adolescents (Alvares et al., 2020; Kraper et al., 2017). We found a significant difference ($M_{diff} = 25.38$, $t = 8.91$, $p < 0.001$) between mean full-scale IQ ($M = 103.87$) and mean adaptive behavior score ($M = 78.49$), indicating that our participants' adaptive behavior scores were lower than would be expected given their full-scale IQ.

Predictors of adaptive behavior

To determine whether motor skills independently predicted adaptive behavior over and above ADOS-2 and full-scale IQ scores, we investigated whether motor skills predict adaptive behavior in autistic children and adolescents by regressing adaptive behavior standard scores onto age, ADOS-2 calibrated severity scores, full-scale IQ scores, and movement total scores with a linear regression (full model $R^2 = 0.31$). Results indicated that age ($F_{1,40} = 9.76$, $b = -1.59$, $SE = 0.51$, $p = 0.003$, Cohen's $f^2 = 0.24$, $\Delta R^2 = 0.17$, Figure 1) and movement total score ($F_{1,40} = 5.67$, $b = 1.81$, $SE = 0.76$, $p = 0.022$, Cohen's $f^2 = 0.14$, $\Delta R^2 = 0.10$, Figure 1) were significantly associated with adaptive behavior standard scores. ADOS-2 calibrated severity scores and, as expected, full-scale IQ scores were not significantly associated with adaptive behavior standard scores ($p > 0.05$). This indicates that participants with higher movement total scores had higher adaptive behavior scores, even when controlling for ADOS-2 and IQ scores.

To further investigate these relations, we regressed adaptive behavior standard scores onto age, ADOS-2

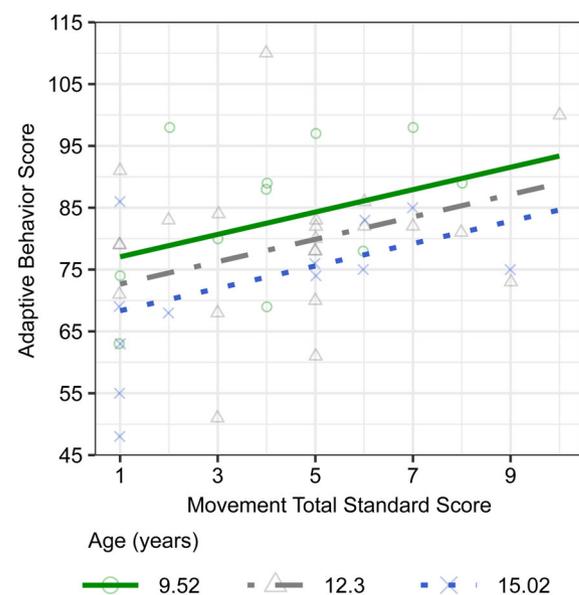


FIGURE 1 Movement total standard scores and age are associated with adaptive behavior scores in autistic children and adolescents. Ages plotted indicate the 25th percentile (9.52 years), mean (12.30 years), and 75th percentile (15.02 years) of the sample. Point shapes indicate 25th percentile and below (circle), between 25th and 75th percentile (triangle), and 75th percentile and above (x)

calibrated severity scores, individual component scores of full-scale IQ (i.e., verbal comprehension, perceptual reasoning), and the individual component scores of the movement total scores (i.e., manual dexterity, aiming and catching, balance; full model $R^2 = 0.35$). Results indicated that age ($F_{1,37} = 9.96$, $b = -1.63$, $SE = 0.52$, $p = 0.003$, Cohen's $f^2 = 0.27$, $\Delta R^2 = 0.17$) and manual dexterity standard scores ($F_{1,37} = 4.75$, $b = 2.12$, $SE = 0.97$, $p = 0.036$, Cohen's $f^2 = 0.13$, $\Delta R^2 = 0.08$) were significantly associated with adaptive behavior standard scores. Perceptual reasoning trended toward

significance ($F_{1,37} = 3.79$, $b = -0.26$, $SE = 0.13$, $p = 0.059$, Cohen's $f^2 = 0.10$, $\Delta R^2 = 0.07$). ADOS-2 calibrated severity scores, verbal comprehension scores, aiming and catching scores, and balance scores were not significantly associated with adaptive behavior standard scores ($ps > 0.05$). This indicates that participants with higher manual dexterity scores, and potentially higher perceptual reasoning scores, had higher adaptive behavior scores.

DISCUSSION

Motor skills are associated with autistic individuals' adaptive behavior scores. Specifically, autistic individuals' manual dexterity explains a significant proportion of the variability in their adaptive behavior scores even when controlling for ADOS-2 scores, verbal comprehension, perceptual reasoning, and other motor skills. These results are highly impactful, clearly illustrating the need for further understanding of the role of motor difficulties, especially manual dexterity difficulties, in autistic individuals' adaptive behavior.

In our exploratory correlation analyses, overall motor skills were associated with adaptive behavior, full-scale IQ, and perceptual reasoning. Additionally, manual dexterity was associated with verbal comprehension. This supports previous developmental research in autistic and neurotypical children indicating that motor skills are foundational to the development of cognitive (Cameron et al., 2016; Soska et al., 2010), language (Bhat, 2021; Libertus & Violi, 2016; West et al., 2019;), and social skills (Dziuk et al., 2007; Lidstone & Mostofsky, 2021; Yu & Smith, 2017) across infancy and childhood. These associations between motor skills and other domains across a wide age range indicate potentially reciprocal developmental relations. For example, children who struggle with motor skills may have difficulty keeping up with their peers when playing games on the playground. This limits their opportunities for social engagement with peers, as well as opportunities to practice and refine their communication strategies. Indeed, motor-based play settings may be a stronger differentiator between autistic and neurotypical children than social-based play settings, further highlighting the importance of motor skills in adaptive behavior (MacDonald, Hatfield, & Twardzik, 2017). Conversely, children who have difficulty engaging socially with their peers may be less likely to engage in physical play with peers that would further develop their motor skills.

Given known heterogeneity in the severity and prevalence of different autistic traits (McCormick et al., 2020; Wolfers et al., 2019), it is important to consider that motor skills may support or impede functional ability differently across the spectrum. For example, autistic children with lower early motor skills have less frequent or effective use of gestures (Taverna et al., 2021) and have

less variable play behaviors (Restall & Magill-Evans, 1994), which may be reflected in higher ADOS-2 calibrated severity scores and/or higher social-communication domain scores (MacDonald et al., 2014). More research is needed to understand the interaction of multiple skill domains across development in autism.

Overall, motor difficulties play a substantial role in children's adaptive behavior and in turn, their quality of life. Untreated motor difficulties among autistic children and adolescents may impact their mental health negatively by increasing the likelihood of social isolation and lower self-esteem (Tamplain & Miller, 2020). It may also impact their physical health by reducing their likelihood to engage in physical activity (MacDonald et al., 2011; Tyler et al., 2014), increasing the risk of chronic health conditions like obesity (Curtin et al., 2010). Furthermore, children with clinically significant motor difficulties (i.e., developmental coordination disorder) report reduced quality of life (Karras et al., 2019; Redondo-Tébar et al., 2021; Zwicker et al., 2018). There is substantial research from the fields of kinesiology, physical therapy, and occupational therapy on improving young children's motor skills and educators and clinicians in early childhood settings are capable of implementing these interventions (Logan et al., 2012; Robinson et al., 2012). Given the breadth of established motor interventions for young children, motor skills are of particular interest for supporting and improving autistic individuals' adaptive behavior and thus their quality of life. This research should be adapted to serve as a starting point for the development of motor skill interventions targeting the specific difficulties experienced by autistic individuals.

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We thank all of the children, adolescents, and caregivers who participated in this research. Out of respect for preferences expressed by many autistic self-advocates in our studies and in the community, we have chosen to use identity-first (rather than person-first) language throughout this manuscript. In doing so, it is not our intention to diminish or invalidate the preferences or perspectives of those who prefer person-first language. We continue to welcome feedback on ways that we can effectively partner with the autistic community to advocate for respect, acceptance, inclusion, and representation in research.

ETHICS STATEMENT

This study was approved by the North Texas Regional Institutional Review Board.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

Data available upon reasonable request from the authors.

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SUPPORTING INFORMATION

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