HHS Public Access

Author manuscript

Autism Res. Author manuscript; available in PMC 2023 February 19.

Published in final edited form as:

Autism Res. 2023 January ; 16(1): 208–229. doi:10.1002/aur.2870.

Multidimensional motor performance in children with autism mostly remains stable with age and predicts social communication delay, language delay, functional delay, and repetitive behavior severity after accounting for intellectual disability or cognitive delay: A SPARK dataset analysis

Anjana Bhat[1,2,3]

[1]Department of Physical Therapy, University of Delaware, Newark, Delaware, USA

[2]Biomechanics & Movement Science Program, University of Delaware, Newark, Delaware, USA

[3]Department of Psychological & Brain Sciences, University of Delaware, Newark, Delaware, USA

Abstract

When motor difficulties continue into adolescence/adulthood, they could negatively impact an individual with autism spectrum disorder (ASD)'s daily living skills, physical fitness, as well as physical and mental health/well-being. Few studies have examined motor difficulties in children with ASD as a function of sex or age; however, greater cognitive challenges are associated with worse general motor performance. Based on the Developmental Coordination Disorder-Questionnaire (DCD-Q) data from the SPARK study sample, 87%–88% children with ASD were at-risk for a general motor impairment that persisted until 15 years and was related to their core and co-occurring difficulties. Bhat et al. confirmed motor difficulties in children with ASD on *multiple motor dimensions* that predicted core and co-occurring conditions after accounting for age and sex. However, presence of intellectual disability (ID) or cognitive delay was not controlled in the previous analysis. Additionally, the effects of age, sex, and cognitive ability on multidimensional motor difficulties of the SPARK sample have not been discussed before. Therefore, this analysis examines the effects of age, sex, and cognitive ability (presence of ID or level of cognitive delay) on the motor performance of children from the SPARK sample using the DCD-Q. Except fine motor skills, multiple motor domains did not change with age in children with ASD. Females without ID improved their fine motor scores with age, and performed better compared to males without ID. Children with ASD and ID had greater motor difficulties across multiple motor domains than those without ID. Even after controlling for age, sex, and presence of ID/cognitive delay; motor performance was predictive of social communication skills, repetitive behavior severity, as well as language and functional delays. Gross motor skills contributed more than fine motor and general motor competence skills in predicting social communication delay.

Correspondence: Anjana Bhat, Department of Physical Therapy, University of Delaware, Newark, DE 19713, USA. abhat@udel.edu.

CONFLICT OF INTEREST

The author has received no other financial support for conducting this research. I have no other conflicts of interest to report.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

However, fine motor and general motor competence skills contributed more than gross motor skills in predicting repetitive behavior severity and language delay. Both, fine and gross motor skills predicted functional delay. In light of consistent findings on motor difficulties in children with ASD, adding motor issues as a specifier within the ASD definition could provide a clear clinical route for movement clinicians to address motor difficulties of individuals with ASD.

Lay Summary

This study examined the effects of age, sex, and cognitive ability on multiple motor domains of children with autism spectrum disorder (ASD). For the most part, multiple motor difficulties continued to persist until 15 years in both males and females with ASD. Children with ASD and ID had greater motor difficulties across multiple motor domains than those without ID. While all motor domains were predictive of core and co-occurring conditions of children with ASD, gross motor skills contributed more to the prediction of social communication skills and fine motor and general competence skills contributed more to the prediction of repetitive behaviors and language delay. Both, fine and gross motor skills predicted functional delay. Diagnosticians should recommend systematic motor screening and refer for further evaluations and treatments for children at-risk for and diagnosed with ASD. Motor advocacy and enhanced public/clinical community awareness is needed to fulfill the unmet motor needs of children with ASD.

Keywords

ASD definition; language; motor (control, system); motor assessments; motor interventions; motor screening; physical activity; restricted/repetitive behaviors; social cognition; social participation

INTRODUCTION

Autism spectrum disorder (ASD) is a highly prevalent developmental disorder with 1 in 44 children in the United States having an ASD diagnosis (Maenner et al., 2021). ASD is defined as a social communication disorder within the DSM-V based on two diagnostic criteria: (a) social communication difficulties such as poor social reciprocity, non-verbal communication, and relationship building and (b) the presence of restricted and repetitive behaviors/interests such as motor stereotypies, inflexible routines, fixed interests, and sensory difficulties (American Psychiatric Association, 2013). The DSM-V also defines specifiers for ASD such as co-occurring, intellectual and language impairments in addition to children's core ASD symptoms (e.g., a child with autism and intellectual impairment). There is a growing debate on whether the definition of ASD should be modified to include motor impairments as a criterion (if specific to ASD) or a specifier (if present in ASD and other cooccurring conditions such as intellectual disability [ID]) given the significant body of evidence supporting the high prevalence of motor difficulties in ASD (Belmonte, 2022; Bhat, 2020, 2021, 2022; Bhat et al., 2022; Bishop et al., 2022; Ketcheson et al., 2021; Licari et al., 2020). Recently, Bhat et al. (2022) found that based on the Developmental Coordination Disorder Questionnaire (DCD-Q) data obtained from a large sample of children with ASD from the SPARK study (N = 13,887), multidimensional motor performance (including visuomotor, multilimb coordination, fine motor, and general coordination) predicted core (social communication delay and repetitive

behavior severity) and co-occurring (cognitive, language, and functional delays) difficulties of children with ASD even after controlling for age and sex. However, it is still unclear whether these predictive relations will persist even after controlling for parent-reported cognitive factors such as the presence of ID or level of cognitive delay. In addition, the previous papers in this series (Bhat, 2021; Bhat et al., 2022) did not discuss age-, sex-, and cognition-based differences in various motor domains of the SPARK sample. Hence, this analysis will examine the effects of age, sex, and presence of ID/level of cognitive delay on multidimensional motor performance of children with ASD from the SPARK study using the DCD-Q measure. In addition, predictive relations between the DCD-Q and other core and cooccurring conditions using measures such as the Social Communication Questionnaire (SCQ), Repetitive Behavior Scales-Revised (RBS-R), and parent-reported delays in language and function will also be examined after controlling for presence of ID or level of cognitive delay.

Age-related motor differences in ASD

Children with ASD present with a range of motor difficulties including gross motor difficulties in visuomotor/upper-limb coordination, balance, and bilateral/whole-body coordination during standardized motor tasks. They also present with functional difficulties during walking (e.g., toe walking or wide base of support) and other locomotor patterns such as difficulty performing complex skills requiring certain movement forms (e.g., long jump, single-leg hop, etc.) as well as difficulties with daily living skills of dressing, carrying objects, and planning complex motor sequences (e.g., when playing a sport) (Ament et al., 2014; Bhat et al., 2011; Fournier et al., 2010; Green et al., 2009; Jansiewicz et al., 2006; Kaur et al., 2018; Licari et al., 2020; Miller et al., 2021; Wang et al., 2022). Furthermore, they have significant fine motor difficulties during hand dexterity tasks, drawing, cutting and copying of shapes, writing legibly, as well as functional tasks of tying shoelaces, buttoning and zipping, and so forth (Bhat et al., 2018; Fears, Palmer, & Miller, 2021; Fleury et al., 2013; Kaur et al., 2018; Kushki et al., 2011; Shield et al., 2017).

The few studies on developmental differences in motor performance during childhood and adolescence report modest to no improvements with age (Bhat, 2020; Biscaldi et al., 2014; Fournier et al., 2010; Van Waelvelde et al., 2010). Fournier et al.'s (2010) meta-analyses found comparatively smaller effects for ASD-related motor differences in older adolescents and adults with ASD compared to younger children with ASD. Nevertheless, they reported large effects for ASD-related motor differences in all age groups compared to age-matched, control groups (Fournier et al., 2010). Biscaldi et al. (2014) also reported stable motor difficulties in static/dynamic balance and coordination in children and adults with ASD between 6 and 29 years. A recent SPARK study analysis replicated this finding with 87% of the sample presenting with a risk for general motor difficulties in children with ASD that did not change between 5 and 15 years (Bhat, 2020). Nevertheless, motor services such as occupational and physical therapy (OT and PT) are known to reduce with increasing age along with increase in sedentary/physical inactivity time; which seems counterintuitive if motor difficulties in children with ASD are not reducing with age (Bremer & Cairney, 2020; Dahlgren et al., 2021; Monz, Houghton, Law, & Loss, 2019; Srinivasan et al., 2014, 2021). For example, youth with ASD showed a decrease in light and moderate to

vigorous physical activity levels between 9 and 18 years compared to age-matched, typically developing children; along with more time spent engaging with video games (Dahlgren et al., 2021). Overall, there seems to be a stable pattern of motor difficulties across childhood and into adolescence which may further negatively impact children with ASD's physical activity levels and subsequently their physical/mental health and well-being (for other factors influencing physical activity levels in ASD refer to Jachyra et al., 2021). Hence, the first aim of this analysis is to examine age-related differences in multidimensional motor performance using the DCD-Q in children with ASD from the SPARK study.

Sex-based motor differences in ASD

Few studies have reported sex-based differences in motor patterns of individuals with ASD (Carter et al., 2007; Crippa et al., 2021; Kopp et al., 2010). Some report better gross motor skills in males compared to females with ASD (Carter et al., 2007; Crippa et al., 2021; Kopp et al., 2010). Carter et al. (2007) reported better gross-motor skills and Crippa et al. (2021) reported better motor anticipation during an experimental reaching task in boys with ASD compared to girls with ASD. In contrast, an earlier report from the SPARK dataset indicated that girls with ASD improved their general motor performance in teenage years compared to boys with ASD who did not show similar rates of improvement (Bhat, 2020). However, both boys and girls with ASD were significantly lower in their general motor performance compared to the typically developing, control children (Bhat, 2020; Nakai et al., 2011). Along these lines, Crippa et al. (2021) did not find any sex-based differences in motor performance using standardized motor measures such as the DCD-Q and Movement Assessment Battery for Children (M-ABC). Hence, the second aim of this analysis focuses on sex-based differences in multidimensional motor performance using the DCD-Q in children with ASD from the SPARK sample.

Cognition-based motor differences in ASD

While there is limited evidence for age or sex-based differences in motor performance of school-age children with ASD; there is growing evidence from small sample studies on how motor difficulties are linked to the intellectual delays of children with ASD. In general, children with ASD with intellectual delays (i.e., lower intelligence quotient or IQ) are known to have greater motor difficulties compared to those with no intellectual delay (i.e., high IQ) (Green et al., 2009; Kaur et al., 2018; Licari et al., 2020). Multiple studies have also shown that fine and gross motor difficulties predict ASD symptoms even after controlling for IQ, indicating that while intellectual delays co-occur with motor delays in ASD, they are also found in children with ASD with no intellectual delay (Bhat, 2021; Bhat et al., 2022; Choi et al., 2018; Green et al., 2009; Kaur et al., 2018; Kopp et al., 2010; Licari et al., 2020; MacDonald et al., 2014; Staples & Reid, 2010).

Taken together, the present study will examine the effects of age, sex, and cognitive ability (*presence of ID or level of cognitive delay*) on multidimensional motor performance (i.e., visuomotor, multilimb coordination, fine motor, and general coordination skills) of children with ASD from the SPARK study. Additionally, multidimensional motor performance will be used to predict core difficulties (social communication and repetitive behaviors) and co-occurring (language and functional) delays after controlling for age, sex, and cognitive

ability. Normalized scoring will be used to compare performance across various motor domains captured by the DCD-Q measure. It is hypothesized that there will be fewer age- and sex-related differences in multidimensional motor performance of school-age children with ASD, but greater differences based on ID or cognitive delay.

METHODS

SPARK study procedures and data access

The SPARK research team has recruited families with one or more children with ASD through more than 21 clinical sites across the US since the start of the study (Feliciano et al., 2018). Families completed several online questionnaires on the SPARK website (https://sparkforautism.org/registration/account_information/). This author has an approved, exempt protocol in place for secondary analysis of de-identified SPARK data with the University of Delaware (UD)'s Human Subjects Review Board. UD has also signed an authorization agreement with the Simons Foundation; after which the first author received access to version 3 of the SPARK study database.

SPARK forms and measures

The SPARK database comprises of several parent questionnaires such as the basic medical screening form, individual data form, and background history form. The basic medical screening form provides demographic information, birth history, professional diagnosis of ASD and other disorders (including ID), as well as other general medical conditions. The individual data form collects details on the child's ASD diagnosis, whether it was professionally confirmed, whether there is a cognitive impairment, the presence of an individualized education plan (IEP) for the ASD diagnosis, and information on receipt of ASD services. Specifically, parents were asked whether their child held *a professionally confirmed diagnosis of ID. 18.6% of the children in the SPARK sample held a diagnosis of ID*.

The background history form lists data on the *cognitive*, language, and functional delay levels of each participant (i.e., at or above, slightly below, or significantly below same-age peers). Proportions of SPARK sample within each subgroup based on each aforementioned delay type is stated in table S1 of Bhat et al., 2022. For level of cognitive delay, 43.8% children were at or above peers, 27% were slightly below peers, and 24.2% were significantly below peers. Data from three parent questionnaires have been analyzed: (a) the DCD-Q (Schoemaker et al., 2006; Wilson et al., 2009), (b) the SCQ—Lifetime (Berument et al., 1999), and (c) the RBS-R (Lam & Aman, 2006). Inclusion/exclusion criteria for this sample have been discussed in a related previous publication Bhat (2021) (N = 13,887). Note that the 13,887 sample reported in the previous papers and used in the current analysis are identical and include children with a cognitive impairment/ID.

Developmental Coordination Disorder-Questionnaire

The DCD-Q shown in Table 1 is a 15-item parent questionnaire used to screen for gross- and fine-motor performance during everyday functions/play within the child's natural environment (Schoemaker et al., 2006; Wilson et al., 2009). It has high internal consistency

(>0.87) and sensitivity (70%–92%) when validated against the Movement ABC assessment in a general, clinically referred sample as well as children with ASD (Green et al., 2009; Schoemaker et al., 2006; Van Damme et al., 2022). The questionnaire includes various motor skills such as ball skills (e.g., hitting or catching a ball), complex body coordination skills (e.g., jumping, running, etc.), fine motor skills (e.g., writing, cutting, etc.), and general motor abilities (e.g., quickness, clumsiness, fatigability, etc.). These skills are categorized into three subscales: Control during movement (CDM, six items, Q01–Q06), fine motor coordination (FM, four items, Q07–Q10), and general coordination (GC, five items, Q11–Q15). Following a recent factor analysis (FA), Bhat et al. (2022) recommended using a five-factor solution for children with ASD as it revealed a more unique pattern of motor delay in the ASD population. The five-factor DCD-Q subdomains include CDM1 (three visuomotor/ball items, Q01–Q03), CDM2 (three multilimb coordination/planning items, Q04–Q06), the standard FM subdomain (four items, Q07–Q10), GC1 (three items, Q11–Q13), and GC2 (two items, Q14–Q15) subdomains. The total final score is the sum of the individual subdomain scores. The total and subdomain scores have been reported in previous papers; therefore, in this analysis, the total and subdomain scores (standard and FA-based) were normalized by the number of items within each subdomain to compare performance across different motor subdomains.

Definite motor impairment or suspect DCD (<10th percentile) is determined based on the final score cutoffs provided by the creators, which differ for different age groups. For example, these cutoffs include a score <47 for children between 5 years and <8 years, a score below 56 for children between 8 years and <10 years, and a score <58 for children between 10 and 15 years. Based on these criteria, an assignment of risk for DCD (1 = Yes or 0 = No) is provided for each participant. A DCD diagnosis is typically confirmed with a follow-up, standardized motor assessment, and clinical judgment of a trained movement clinician. Note that the positive predictive value of the DCD-Q with a clinical motor assessment such as the Movement ABC is 80%−92% (i.e., children who are at-risk for a motor impairment using the DCD-Q are likely to perform poorly on the Movement ABC motor measure) (Green et al., 2009; Van Damme et al., 2022). The risk for DCD/motor impairment in this sample has already been reported in previous papers, Bhat (2020, 2021). This paper focuses on the various DCD-Q subdomain scores and the effects of age, sex, and cognitive ability (ID or level of cognitive delay).

Social Communication Questionnaire

The SCQ is a 40-item parent questionnaire (with a Yes/No response format) to screen for autistic symptoms and social communication delay in children above 4 years of age with a mental age of at least 2 years (Berument et al., 1999). The SCQ has moderate internal consistency (0.7–0.8) and sensitivity (80%) when compared against the Autism Diagnostic interview Revised (ADI-R) and has been validated in children with ASD (Green et al., 2009; Schoemaker et al., 2006; Van Damme et al., 2022). The Lifetime version of the SCQ used here provides a total SCQ score. If the total score is 12 or above, it indicates a social communication delay and a higher likelihood to be on the autism spectrum. The cutoff of 12 is a research-recommended, sensitive cut-off, and was implemented in the present study (Daniels et al., 2011; Lee et al., 2010; Marvin et al., 2017; Zwaigenbaum et al., 2015).

Repetitive Behavior Scales-Revised

The RBS-R is a 43-item parent report measure to characterize the repetitive behaviors of children with ASDs (Lam & Aman, 2006). The RBS-R has moderate internal consistency (0.78–0.9) and test–retest reliability (70%) when administered in individuals with ASD (Lam & Aman, 2006). Each item/question is scored on a 4-point scale: 0 (no such behavior), 1 (mild problem), 2 (moderate problem), and 3 (severe problem), therefore the total score ranges between 0 and 129 with higher score indicating more repetitive behavior. The total RBS score was used as a measure of repetitive behavior severity.

Subgrouping analysis

As reported in past publications (Bhat, 2021; Bhat et al., 2022), the entire SPARK sample is divided into five subgroups/categories based on scoring ranges defined for SCQ scores, RBS-R scores, and DCD-Q scores using each measure's sample mean and SDs (subgrouping details provided in Bhat, 2021 and table S1 of Bhat et al., 2022). Subgrouping categories included very low, low, high, very high, and extremely high for social communication impairments (SCI) or repetitive behavior (RB) severity. Missing data for scores was only 0.6% for the RBS-R scores, but no data was missing for the DCD-Q and SCQ scores because presence of valid DCD-Q and SCQ scores was a key inclusion criterion.

Data extracted from parent reported levels of *cognitive*, functional, and language delays are also presented in table S1 of Bhat et al. (2022). The parent-reported outcome data were divided into three subgroups based on the reported level of *cognitive*, functional, and language delay compared to peers (i.e., at or above, slightly below, or significantly below peers). ~5% cognitive, ~3% functional, and ~3% language delay information was missing for the present sample. Note that results examining the effects of level of cognitive delay (instead of ID-related effects) and their influence on core and co-occurring difficulties are reported within the Supporting Information of this paper, whereas the ID-related effects are presented within the publication. Demographic information for this sample has been reported previously in table 1 of Bhat et al. (2022).

Statistical analysis

Statistical analyses were conducted using JMP Pro 16.0 (JMP, Inc). As discussed in Bhat et al. (2022), the DCD-Q has three standard subdomains (CDM—control during movement, FM—fine motor, and GC—general coordination) as well as five FA-based subdomains: CDM1/visuomotor, CDM2/multilimb coordination and planning, GC1, and GC2 as well as the FM subdomain, which is identical to the standard FM subdomain (Bhat et al., 2022). Pearson correlations between age and DCD-Q total and subdomain scores (standard and FA-based) were calculated. Spearman rank correlations between DCD-Q total and subdomain scores (standard and FA-based) and sex and presence of ID/levels of cognitive delay were calculated. Three-way analysis of variances (ANOVAs) were used to study the effect of age in years, sex, and presence of ID (yes = 1, no = 0, Figures 1 and 2 and Tables 1–7 in publication) or level of cognitive delay (0 = no delay, 1 = some delay, 2 = significant delay, Figures S1 and S2 and Tables S1–S4) on total and subdomain scores (standard and FA-based). Ordinal logistic regression analyses were used to predict subgroup assignment (i.e., subgroup 1–5 based on SCI and RB severity or subgroup 1–3 based on language and

functional delay). For each regression model, effects of age, sex, and presence of ID (see Table 7)/cognitive delay (see Table S4) were included and accounted for. Four different models were developed using total scores, original subdomain scores, FA-based subdomain scores, and item-level DCD-Q scores as predictors, with age, sex, and presence of ID or levels of cognitive delay. The Wald's chi-squared test values are reported for predictors that significantly contributed to a given model. For all analyses, statistical significance was modified based on *p* value thresholds set after Bonferroni corrections.

RESULTS

Age, sex, and ID-related differences in motor performance

The three-way ANOVA between age, sex, and presence of ID revealed a main effect of age for Total, FM, CDM1, and CDM2 subdomains, a main effect of sex for FM subdomain only, and a main effect of ID for all subdomains, as well as a sex × ID interaction for FM subdomain only, after Bonferroni corrections (Table 2). Post-hoc *t* tests for *main effect of age* revealed that FM and CDM1 (visuomotor/ball skill) scores improved with age across the three age groups, whereas CDM2 (multilimb coordination/planning) scores worsened with age across three age groups of 5–8 year olds, 9–12 year olds, and 13–15 year olds (*p* values <0.0001, Table 3, Figures 1 and 2). Post-hoc *t* tests for *main effect of sex* revealed that FM and GC1 scores were slightly better in females compared to the males with ASD (*p* values <0.0005, Table 3, Figures 1 and 2). Post-hoc *t* tests for *main effect of presence of ID* revealed that for all subdomain scores except GC2, children with no ID performed better than those with ID (*p* values <0.0001, Table 3, Figures 1 and 2). Post-hoc analyses for the *sex* × *ID interaction* for the FM subdomain scores revealed that females with ASD (10.7 ± 0.10) scored higher than males with ASD (9.8 ± 0.05) in the no ID subgroup ($p < 0.0006$); but sex-related differences were not seen in the subgroups with ID (Females: 7.5 ± 0.16, Males: 7.3 ± 0.08). In addition, in both, males and females with ASD, presence of ID lowered FM performance scores for both groups (see aforementioned values, *p*s < 0.0001). While there are small-age related improvements in FM and CDM1 (visuomotor/ball skill) scores, it is important to note that the normalized scores for the 50th percentile of the sample ranged between 1.67 and 3.00 (on a scale of 1–5, with 5 being best performance of the stated skill) indicating significant motor difficulties (Table 4). Similarly, the normalized scores for the 75th percentile of the sample ranged between 2.60 and 4.00, indicating some to significant motor difficulties (Table 4). Furthermore, these normalized scores did not change by 15 years of age (range for 50th percentile: 1.67–2.67, range for 75th percentile: 2.67–3.67) (Table 5).

In terms of correlations, the total, CDM (gross motor), FM (fine motor), and CDM1 (visuomotor/ball) scores slightly improved with age whereas CDM2 scores (multilimb coordination/planning) seem to slightly worsen with age (Table 6). Based on sex, overall, females had slightly better FM skills compared to males. Based on ID, all DCD-Q subdomain scores were worse in children with ID compared to those without. Note that the aforementioned analyses were redone using level of cognitive delay as the cognitive factor (instead of presence of ID); and the major findings do not differ as reported in Figures S1 and S2 and Tables S1–S4.

Predicting core and comorbid difficulties using various motor dimensions while controlling for age, sex, and ID

Ordinal logistic regression analyses were used to predict subgroup assignment based on level of social communication delay, repetitive behavior severity, language, and functional delays using age, sex, presence of ID, and DCD-Q total, original subdomain (CDM, FM, GC), FA-based subdomain (CDM1, CDM2, FM, GC1, GC2), and item-level (Q1–Q15) scores as predictors. The Wald chi-squared test shows the contributions of significant predictors in Table 7.

For the *SCI categories model* using the *total DCD-Q score* as a predictor, in the order of most to least importance, the total DCD-Q score, child's age, presence of ID, and sex were significant contributors to the model. For the SCI categories model using *standard subdomain scores* as predictors, in the order of most to least importance, child's age, CDM score, FM score, presence of ID, GC score, and sex were significant contributors to the model. For the SCI categories model using *FA-based subdomain scores* as predictors, in the order of most to least importance, child's age, FM score, presence of ID, CDM1 score, GC1 score, CDM2 score, and sex were significant contributors to the model. For the SCI categories model using *item scores* as predictors, apart from child's age, presence of ID, and sex, 9 out of 15 items including Q06/plans, Q03/hits ball, and Q09/writing effort were significant contributors to the model.

For the *RB categories model* using the *total DCD-Q score* as a predictor, in the order of most to least importance, the total DCD-Q score, child's age, and presence of ID were significant contributors to the model. For the RB categories model, using *standard subdomain scores* as predictors, in the order of most to least importance, GC score, FM score, child's age, and presence of ID were significant contributors to the model. For the RB categories model using *FA-based subdomain scores* as predictors, in the order of most to least importance, FM score, GC2 score, child's age, presence of ID, GC1 score, and CDM2 score were significant contributors to the model. For the RB categories model using *item scores* as predictors, apart from child's age and presence of ID, 9 out of 15 items including Q09/writing effort, Q13/quick competent, and Q14/bull in a china shop were significant contributors to the model. Note that sex was not a contributor to any of the RB category models.

For the *language delay model* using the *total DCD-Q score* as a predictor, in the order of most to least importance, presence of ID, child's age, and the total DCD-Q score were significant contributors to the model. For the language delay model using *standard subdomain scores* as predictors, in the order of most to least importance, presence of ID, age, FM score, GC score, and CDM score were significant contributors to the model. For the language delay model using *FA-based subdomain scores* as predictors, in the order of most to least importance, presence of ID, FM score, child's age, GC2 score, CDM1 score, GC1 score, and CDM2 score were significant contributors to the model. For the language delay model using *item scores* as predictors, apart from child's age and presence of ID, 10 out of 15 items including Q06/plans, Q10/cuts, and Q15/does not fatigue easily were significant contributors to the model. Note that sex was not a contributor to any of the language delay models.

For the *functional delay model* using the *total DCD-Q score* as a predictor, in the order of most to least importance, the total DCD-Q score, presence of ID, and sex were all significant contributors to the model. Notably, age was not a contributor to this model. For the functional delay model using *standard subdomain scores* as predictors, in the order of most to least importance, FM score, presence of ID, CDM score, GC score, and sex were significant contributors to the model. Again, age was not a contributor to this model. For the functional delay model using *FA-based subdomain scores* as predictors, in the order of most to least importance, FM score, presence of ID, GC1 score, CDM2 score, CDM1 score, and sex were significant contributors to the model. Once again, age was not a contributor to this model. For the functional delay model using *item scores* as predictors, apart from presence of ID, child's age, and sex, and 9 out of 15 items including Q13/quick and competent, Q06/plans, and Q10/cuts, were significant contributors to the model. Note that the aforementioned analyses were redone using level of cognitive delay as the cognitive factor (instead of presence of ID) and the results do not differ as reported in Figures S1 and S2 and Tables S1–S4.

DISCUSSION

This analysis examined the changes in multidimensional motor performance using the DCD-Q measure as a function of age, sex, and two cognitive factors (either presence of ID or level of cognitive delay) in children with ASD from the SPARK study sample. Fine motor and visuo-motor/ball skills improved with age whereas multilimb coordination/planning skills somewhat worsened with age. Fine motor skills were slightly better in females compared to the males with ASD. For all (total and subdomain) DCD-Q scores except the GC2 subdomain, children with no ID performed better on various motor dimensions than those with ID. For the FM subdomain, females with ASD scored slightly higher than males with ASD in the no ID subgroup; but sex-related differences were not seen in the subgroups with ID. Overall, while there are small age-related improvements in fine motor and visuomotor/ball skills, the overall findings indicate some to significant motor difficulties between 5 and 15 years in majority of the SPARK sample. Correlations confirmed that gross motor, fine motor, and visuomotor/ball skills slightly improved with age. Females with ASD had slightly better fine motor skills compared to males with ASD. The presence of ID was associated with poor motor performance for all subdomains of the DCD-Q. Lastly, even after controlling for age, sex, and presence of ID; motor performance was predictive of social communication skills, repetitive behavior severity, and functional delay in children with ASD. When predicting language delay, the contributions of ID were somewhat stronger; however, after controlling for ID, all subdomains of the DCD-Q were still predicting language delay. Gross motor skills contributed more than fine motor and general motor competence skills in predicting social communication delay. However, fine motor and general motor competence skills contributed more than gross motor skills in predicting repetitive behavior severity and language delay. Both, fine and gross motor skills contributed to functional delays of children with ASD. Note that the aforementioned results are very similar to the findings when level of cognitive delay is used as a predictor instead of presence of ID as explained in Supporting Information, hence, the results using level of cognitive delay are not separately discussed here.

While there are small improvements in certain motor skills, overall, there is a stability in motor difficulties seen throughout childhood and adolescence in children with ASD

Children in the present study showed small age-related improvements in fine motor and visuomotor/ball skills as well as a small age-related decline in multilimb coordination/ planning skills. Multiple other studies have reported a stable pattern of motor difficulties in children with ASD throughout childhood and adolescence with some developmental trends (Bhat, 2020; Biscaldi et al., 2014; Van Waelvelde et al., 2010; Wang et al., 2022). A recent meta-analysis of 114 motor outcome studies ($N = 6423$) did not find any moderating effects of age on gross motor performance (Wang et al., 2022). Biscaldi et al. (2014) reported no age-related changes in timing-based, fine motor, and balance tasks except some improvement in diadochokinesis (i.e., hand/foot coordination) in children versus adolescents with ASD that is consistent with the fine motor and visuomotor/ball skill improvements found in the present study. However, a decline in multilimb coordination/planning has not been reported earlier. A more cautious approach would be to recognize the overall low motor performance across multiple dimensions and the stable pattern of some to significant motor difficulties during childhood and adolescence. This persistent motor delay in school-age children with ASD warrants more recognition, screening, assessment, and intervention throughout childhood and not just in the first 3 years of life.

Females with ASD have slightly better fine motor skills than males with ASD

Few studies have reported differences in motor performance between females and males with ASD. In this study, females without ID/cognitive delay had better fine motor performance compared to males without ID, whereas there were no major differences in females and males with ID/cognitive delay. However, for the various other motor domains —visuomotor/ball, multilimb coordination/planning, and general motor competence skills; there were no sex-based differences. The specific improvements in fine motor skills in females with ASD may be attributed to their predilections to visual/fine arts and improved motor skills with development. 80% of the SPARK study sample was receiving occupational therapy (OT) services that are known to target children's fine motor skills, which could have contributed to improved fine motor performance in the females with ASD. Past studies have found better gross motor skills and motor anticipation in boys compared to girls with ASD (Carter et al., 2007; Crippa et al., 2021). The more important finding is the lack of motor differences in visuomotor/ball, multilimb coordination/planning, and general motor competence skills. This finding is consistent with Crippa et al. (2021) who also reported a lack of sex-based motor differences based on data from the DCD-Q questionnaire as well as the Movement-ABC standardized assessment. The meta-analysis of several motor studies by Wang et al. (2022) also did not find any moderating effects of sex on gross motor performance and resembles the findings from the SPARK study. Taken together, these findings confirm that motor services should be made available to all children with ASD regardless of sex.

Children with ASD and ID/cognitive delay had greater motor difficulties compared to those without ID/cognitive delay

The greater prevalence of general motor differences in children with ASD with ID compared to those without ID in the SPARK sample was recently reported by Ketcheson et al. (2021). Findings from the present study further validate that performance on multiple motor dimensions—visuomotor/ball, multilimb coordination/planning, fine motor, and certain general motor competence skills is more affected in children with ASD and ID/cognitive delay compared to those without ID/cognitive delay. There is copious evidence in the literature in support of this finding and past studies have reported a significant effect of IQ on motor difficulties of children with ASD (Ghaziuddin & Butler; 1998; Mari, Castiello, Marks, Marraffa, & Prior, 2003). In the last decade, studies have recognized that children with ASD with and without ID/cognitive delay have motor difficulties regardless of intellectual delay (Bhat et al., 2011; Jansiewicz et al., 2006; Ketcheson et al., 2021; Kopp et al., 2010; MacDonald et al., 2014). Note that the meta-analysis by Wang et al. (2022) surprisingly did not find a moderating effect of IQ on gross motor performance of individuals with ASD. In contrast, examination of DCD-Q data from the SPARK sample by Ketcheson et al. (2021) showed that although motor difficulties were greater in children with ASD and ID they were also highly prevalent in children with ASD with no ID. Together, these findings underscore the fact that motor issues need more recognition and focused interventions in all children with ASD with unmet motor needs (but children with ID/cognitive delay may need more motor services) to prevent secondary consequences of physical inactivity, motor dislike, and reduced social participation in the long-term.

Gross motor skills better predicted social communication delay than fine motor skills, even after controlling for cognitive ability

Even after controlling for age, sex, and presence of ID/cognitive delay, general motor performance as measured by total DCD-Q scores strongly predicted core (social communication and repetitive behavior categories) and co-occurring (language and functional) delays/differences; however, the motor contributions in predicting language delays were somewhat lowered by adding ID/cognitive delay as a factor. Even after controlling for ID/cognitive delay, gross motor, fine motor, and general motor competence skills predicted core (social communication and repetitive behavior categories) and cooccurring (language and functional) delays. However, gross motor skills (visuomotor > multilimb coordination/planning) contributed more than fine motor skills to the prediction of social communication delay and fine motor and general coordination (motor competence) skills contributed more than gross motor skills to the prediction of repetitive behavior severity.

A meta-analysis by Wang et al. (2022) on 114 studies using standardized motor assessments found large effects for gross motor difficulties in children with ASD; not moderated by children's IQ levels, and modestly linked to their social communication difficulties. Specifically, large effect sizes for motor differences were reported for object control, strength/agility, balance/coordination, imitation, and locomotor skills (vs. simple reaching skills), based on standardized motor measures (vs. kinematic measures), and for upper-limb and whole-body tasks (vs. lower-limb tasks). Using a smaller group of studies (14 studies,

N = 654), Wang et al. (2022) also found significant but modest (0.27) correlations between motor and social communication difficulties in individuals with ASD. Motor delays are one of the earliest markers in children who develop ASD in the future and enable infants to use their goal-directed actions to communicate with caregivers and peers using head turns, gestures, and physical approaches. Motor delays and differences are known to increase in magnitude with development (Lloyd et al., 2013) and their lack of motor play with peers can lead to missed opportunities for building social connections with others and might explain the linkages between motor and social communication development in children with ASD.

Fine motor and general motor competence skills predicted repetitive behavior severity more than gross motor skills even after controlling for cognitive ability

After controlling for ID/cognitive delay, fine motor and general motor competence skills contributed more than gross motor skills to the prediction of repetitive behavior severity. Few studies have examined motor and repetitive behavior linkages in individuals with ASD (Bhat, 2021; Bhat et al., 2022; Radonovich et al., 2013; Ravizza et al., 2013; Uljarević et al., 2021). Fine motor performance on a rhythmic finger tapping task was associated with the repetitive behavior severity of adolescents with ASD (Ravizza et al., 2013). It was hypothesized that disordered motor control in adolescents with ASD may contribute to poor response selection or planning of goal-directed actions which then manifests as or is replaced with repetitive behaviors. In sum, the evidence for gross motor—social communication links and the links between fine motor/general motor competence—repetitive behavior severity support the inclusion of motor challenges among the defining criteria for ASD. However, the specificity of motor difficulties in ASD is unclear as this analysis did not include children with other developmental diagnoses such as DCD or attention deficit hyperactivity disorder (ADHD).

Fine motor and general motor competence skills predicted language delay more than gross motor skills even after controlling for cognitive ability

While all three motor skill subdomains were contributors, fine motor and general motor competence skills contributed more to the prediction of language delay even after controlling for ID/cognitive delay. In fact, the addition of ID/cognitive delay as a factor made the contribution of fine motor skills in predicting language delays stand out even more. Relations between fine-motor skills and language development in children with/without ASD have been robustly reported in the literature (Bal et al., 2020; Bedford et al., 2015; Bhat et al., 2012, 2018; Choi et al., 2018; Gernsbacher et al., 2008; Iverson, 2018; LeBarton & Landa, 2019; Shield et al., 2017). Early motor milestones of reaching, sitting, crawling, walking, and object play offer opportunities to verbally/non-verbally communicate with caregivers and receive linguistic inputs from them (Iverson, 2018, 2021). Infants who have a greater likelihood of developing ASD later present with reduced or less variable object exploration behaviors in the first year of life compared to infants with typical likelihood for ASD (Iverson et al., 2018; Kaur et al., 2015; Srinivasan & Bhat, 2016, 2019). Additionally, infants with a greater likelihood of developing ASD produce fewer early, deictic gestures as well as later, symbolic gestures compared to infants with typical likelihood for ASD in early childhood (Iverson, 2018, 2021; Iverson et al., 2018). These alternative early learning experiences may reduce their opportunities for caregiver labeling/scaffolding to

facilitate early vocabulary and subsequent language development (Leezenbaum et al., 2014; Srinivasan & Bhat, 2020).

Fine motor, gross motor, and certain general motor competence skills were most predictive of functional delay even after controlling for cognitive ability

In the present study, fine motor, gross motor (including multilimb coordination/planning), and certain general motor competence skills better predicted parent-reported functional delays, after controlling for ID/cognitive delay. The few studies relating motor and daily living skills in children with ASD have reported linkages between various motor skills and adaptive functioning in children with ASD (Bhat, 2021; Jasmin et al., 2009; Licari et al., 2020; MacDonald et al., 2013). Bhat (2021) and Bhat et al. (2022) found moderate associations between motor performance (gross/fine motor and general motor competence) and functional delays in the SPARK ASD sample. Jasmin et al. (2009) found motor and daily living skill associations in preschoolers with ASD using two different functional measures—Functional Independence Measure (Wee FIM) and the VABS and the Peabody Developmental Motor Scales (PDMS) in preschoolers with ASD. Various motor dimensions such as locomotion, object manipulation, grasping, and visuomotor integration related to the self-care domain of the Wee FIM and/or the personal/daily living domains of the VABS. However, MacDonald et al. (2013) found that fine motor skills of young children with ASD (14–49 months) were more predictive of all adaptive domains on the VABS whereas gross motor skills were more predictive of the daily living skills only. Poor motor performance, perceived motor competence, as well as dyspraxia or difficulty performing complex movement sequences could affect children with ASD's abilities to perform various fine/gross motor daily living skills and further negatively impact their social, communication, and cognitive functioning.

General motor competence skills were linked to core and co-occurring difficulties in ASD, even after controlling for ID/cognitive delay

General coordination (motor competence) skills such as likes sports, learns new motor skills, quick/competent at daily skills, does not seem clumsy, does not fatigue easily contributed more than gross motor skills when predicting repetitive behaviors and co-occurring language delay, even after controlling for ID/cognitive delay. These general motor difficulties will manifest in both fine and gross motor actions and only reinforce the findings of significant motor difficulties in children with ASD that need further recognition and well-defined clinical pathways throughout childhood regardless of sex and IQ. From an intervention perspective, children with ASD may be limited in their sports/physical activity participation, have challenges acquiring new motor skills, may need more time to process/complete complex (multistep) motor functions, may find complex actions challenging, and may fatigue easily (Jachyra et al., 2021). Motor interventions should focus on the aforementioned aspects of movement quality, form/complexity, endurance, and timing through the use of various safe and engaging, individual and small group, physical activity opportunities. Ultimately, such movement experiences should focus on promoting social connections, cognitive flexibility, and overall physical/mental health/well-being. Any movement therapy should emphasize daily living skills that advance functional independence within the context of the child's home, school, and community.

Where do motor issues fit within the ASD definition? Clinical implications for motor screening, assessment, and treatment of children with ASD

The overall implications of Bhat (2020, 2021, 2022), and Bhat et al. (2022) are that motor impairments in children with ASD are pervasive (seen in 87%–88% of the sample), persistent (did not change between 5 and 15 years), substantial (some to significant difficulties), unique (visuomotor/ball, multilimb coordination/planning, fine motor, and general motor competence-related), and predictive of core (social communication and repetitive behavior) and co-occurring (language and functional) conditions in ASD, even after controlling for cognitive ability. These motor impairments are well-explained by the popular disrupted connectivity framework of ASD in that there are various perceptuo-motor and other system pathways affected in children with ASD due to the atypicalities in long-range, inter-regional neural connectivity (review more details in Bhat, 2021; Bhat et al., 2022; Maximo et al., 2014; Nebel et al., 2016; Vasa et al., 2016). The motor findings from the SPARK study join calls for inclusion of motor impairments within the definition of ASD either within the criteria or specifiers (Bhat, 2022; Ketcheson et al., 2021; Licari, 2022; Licari et al., 2020; Miller et al., 2021; Van Damme et al., 2022).

At the 2021 and 2022 Annual Meetings for International Society for Autism Research (INSAR), motor experts expressed the need to include motor issues within the ASD definition because doing so, would give motor issues the recognition to encourage diagnosticians (physicians, pediatricians, neurologists, psychologists, and psychiatrists) to conduct early motor screening and referrals to movement clinicians (OTs and PTs), and address the early motor delays and the increasing motor gaps in childhood, as well as the negative impacts of motor difficulties/dyspraxia on overall development, functioning, physical activity, and social participation in adolescence and adulthood. Few studies have distinguished motor difficulties in children with ASD compared to those with other developmental diagnoses (i.e., ADHD, DCD, and learning disability [LD]). Some studies found similar levels of gross/fine motor difficulties; but greater gestural/praxis difficulties in children with ASD compared to those with DCD or ADHD (Dewey et al., 2007; Kilroy et al., 2022; Macneil & Mostofsky, 2012; Sumner et al., 2016). Others have reported greater or specific motor difficulties in children with ASD compared to those with DCD or ADHD or LD (Caeyenberghs et al., 2016; McPhillips et al., 2014; Van Waelvelde et al., 2010). Given the current evidence it is difficult to claim that motor difficulties in visuomotor/ball, multilimb coordination/planning, fine motor, and general motor competence skills are only seen in children ASD (perhaps with greater severity) compared to other diagnoses. It might be logical to follow the precedent of language impairments (Rosen et al., 2021) and have motor issues be included as a specifier of ASD so that they can be independently addressed by movement experts by developing a well-defined, clinical route for screening, assessment, and intervention.

OT and PT services for individuals with ASD plummet substantially between 3 and 18 years of age with OT services dipping from 52% to 23% and PT services dropping from 48% to 14% at least for the state of Delaware (Srinivasan et al., 2021). The percent receipt of OT (76%–80%) and PT (~32%) services somewhat differs across the entire United States, but those studies also report a decline in OT/PT services with age (Ames et al., 2021; Monz et

al., 2019). Often motor evaluations and services are not recommended to children with ASD because the majority will acquire motor milestones despite some delays. More efforts will be needed to change the mindset of clinicians, educators, and researchers for them to frequently recommend and practice motor screening and assessment/intervention referrals to address the complex and persistent fine and gross motor problems associated with developmental dyspraxia/DCD.

Screening tools such as the Ages-Stages Questionnaire (ASQ), DCD-Q (including the little DCD-Q), and Movement-ABC checklist are quick tools to screen for motor delays in young infants and children (Miller et al., 2021; Van Damme et al., 2022). The DCD-Q is now validated as a motor screener in children with ASD (including its 5-subdomain structure) (Bhat et al., 2022; Van Damme et al., 2022) and the next step should be to further examine the value of the little DCD-Q in young children with ASD as well as adult dyspraxia screeners for adults with ASD (e.g., Adult DCD/Dyspraxia Checklist) (Kirby et al., 2010; Wilson et al., 2015). If a risk for motor impairment is identified, then the next step should be to complete an age-appropriate, full motor assessment such as the Alberta Infant Motor Scale (AIMS) for infants, Peabody Developmental Motor Scale (PDMS) for infants and toddlers, or the Movement-ABC (M-ABC) or Test of Gross Motor Development (TGMD), or the Bruininks–Oseretsky Test of Motor Proficiency (BOT) for school-age children, or the Bruininks Motor Ability test (BMAT) for adults. This would determine the extent and nature of motor impairments which along with family/individual's goals and individual preferences for motor functioning could help determine the next steps for providing effective motor interventions. There is early evidence for the use of creative and general movement interventions based on engaging physical activity ideas using elements of gross-motor coordination/balance training, whole-body coordination games, interpersonal synchrony/turn-taking, as well as social interactions including, listening, singing/conversations, and leading/following that can lead to multisystem, positive effects (Bhat et al., 2021; Cleffi et al., 2022; Kaur et al., 2021; Kaur & Bhat, 2019; Ketcheson et al., 2017; Srinivasan et al., 2021; Srinivasan & Bhat, 2013; Srinivasan, Eigsti, Gifford, & Bhat, 2016; Srinivasan, Eigsti, Neelly, & Bhat, 2016; Srinivasan, Kaur, et al., 2015; Srinivasan, Park, et al., 2015). A recent systematic review found medium to large positive effects of creative movement (music and movement, yoga, and martial arts) on the social communication, cognitive-behavioral, and perceptuo-motor skills of children with ASD (Amonkar et al., 2021).

There is a need for further motor advocacy to increase community awareness about the under-diagnosis (only 15% have a motor delay co-diagnosis in the SPARK sample) and under-treatment (32% receive PT and 13% receive recreational therapies in the SPARK sample) of motor difficulties in children with ASD. Movement clinicians (OTs, PTs, adapted physical educators), ABA therapists and special educators must incorporate evidence-based movement interventions (age-appropriate functional motor skill training, physical activity/exercise, sports participation, or creative movement such as yoga and music and movement individually or in small groups) to make ASD interventions more embodied (i.e., inclusive of movement) and socially embedded to promote multisystem development. Even early on in life, when receiving early intervention (EI), it will be important to identify the mild to moderate motor delays in young children with or at-risk for ASD (i.e., preterm infants and infant siblings) and address them through parent-mediated interventions and/or IDEA-based

EI services and not “wait” until early delays magnify into significant motor difficulties in the future.

Stakeholders such as clinicians/parents of children with ASD and self-advocates with ASD have pointed out the lack of priority given to motor/physical activity interventions during delivery of standard therapies (especially in formative school years) as a clear barrier to promoting motor/physical activity services. For example, sedentary behavioral, speech, and OT interventions are prioritized over gross-motor, PT or physical activity interventions (Campos et al., 2019; Gregor et al., 2018; Jachyra et al., 2021). This is consistent with the service rates reported in the SPARK study sample with 31% receiving PT and 13% receiving recreational therapies (Bhat, 2020). Finally, there is limited research on the value of motor/physical activity interventions for individuals with ASD across the lifespan that assess long-term outcomes of motor functioning, physical activity, and cascading effects on other systems. The few studies exploring barriers to promoting gross motor/physical activity interventions indicate additional systemic/environmental and family-related barriers beyond the individual challenges such as motor difficulties of individuals with ASD (Gregor et al., 2018; Jachyra et al., 2021). Self-advocates and parents expressed the lack of enough physical activity options, the negative experiences associated with current school or community-based programs resulting in exclusion and bullying of individuals with ASD, the lack of ASD expertise among movement clinicians, and the competing burden of providing standard therapies (typically sedentary in nature) as major barriers to promoting motor/physical activity interventions in individuals with ASD (Gregor et al., 2018; Jachyra et al., 2021). In short, adding motor difficulties as a specifier to the ASD definition will give it the recognition needed to bring these issues on the radar of clinicians, caregivers, stakeholders, and funding agencies to enhance their support of such clinical, community, and research programs. Our work as motor advocates does not stop there, and is just the first step to providing effective and meaningful motor screening, assessment, and interventions throughout the lifespan for individuals with ASD including greater priority/access to and funding/development of movement/physical activity programs.

LIMITATIONS

This study’s emphasis on parent report of children’s abilities come with reporting biases. However, parent reports are a feasible method to obtain information from large samples to understand population level trends. Further clinical assessments in larger samples are needed to confirm the pattern of motor difficulties reported by parents. Specifically, measures of cognitive delay reported in the current analysis were relatively less powerful (i.e., parent-reported presence of ID or three levels of cognitive delay compared to same-age peers). Future studies must include more robust measures of intelligence (e.g., an IQ measure). Along these lines, it will be important to study motor performance, functioning, and participation across the lifespan in individuals with ASD by adding more objective, clinical motor assessments (e.g., PDMS, BOT, M-ABC, TGMD, etc.) as well as motor function and participation measures (PEMCY, CAPE, COPM, etc.) to the SPARK study battery.

CONCLUSIONS

The present study examined the SPARK study sample of children with ASD between 5 and 15 years to conduct a multidimensional, motor assessment and predict other core and co-occurring delays/differences based on motor performance while controlling for ID/cognitive delay. Visuomotor/ball, multilimb coordination/planning, fine motor, and general coordination difficulties were uniquely distinguishing motor problems of children with ASD. Gross motor skills were more predictive of social communication delay and fine motor and general motor competence skills were more predictive of repetitive behavior severity and language delay. Both, fine and gross motor skills were predictive of functional delay. The comprehensive analysis of motor impairments in a large ASD cohort across multiple studies (Bhat, 2020, 2021, 2022; Bhat et al., 2022; Ketcheson et al., 2021) provide robust evidence for the inclusion of motor impairments within the definition of ASD at least as a specifier to give it the much-needed recognition and to develop a well-defined clinical route for diagnosticians and interventionists to follow. Given the growing calls to address motor difficulties in the ASD population, diagnosticians should be recommending systematic motor screening, and refer for further motor evaluations and treatments for children at-risk for and newly diagnosed with ASD. Parents, clinicians, and educators in EI and school systems should be made aware of the need to address motor delays/gaps in children with ASD and should not be complacent with a “wait and see” strategy. Motor advocacy and enhanced public/clinical community awareness is urgently needed for children and families who have unmet motor needs. Throughout the lifespan, there is a need to provide greater feasible and enjoyable opportunities for motor/physical activity interventions including greater access and priority to movement therapies including physical and occupational therapy, adapted physical activity, and play/creative movement therapies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

The author is grateful to all SPARK families, SPARK clinical sites, and SPARK staff and truly appreciate obtaining access to the phenotypic data on SFARI Base. Approved researchers can obtain the SPARK population dataset described in this study at https://base.sfari.org/ordering/phenotype/sfari-phenotype by applying for the same at the following website: https://base.sfari.org. This research is supported by the National Institutes of Mental Health through an R01 award (Grant #: R01MH125823-02, PI: Anjana Bhat).

Funding information

National Institutes of Mental Health, Grant/Award Number: R01MH125823-02

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from Simons Foundation. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from https://www.sfari.org/resources/ with the permission of Simons Foundation.

REFERENCES

Ament K, Mejia A, Buhlman R, Erklin S, Caffo B, Mostofsky S, & Wodka E (2014). Evidence for specificity of motor impairments in catching and balance in children with autism. Journal of Autism and Developmental Disorders, 45(3), 742–751. 10.1007/s10803-014-2229-0

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). American Psychiatric Publishing.

Ames JL, Massolo ML, Davignon MN, Qian Y, & Croen L (2021). Healthcare service utilization and cost among transition-age youth with autism spectrum disorder and other special healthcare needs. Autism, 25(3), 705–718. 10.1177/1362361320931268 [PubMed: 32583679]

Amonkar N, Su W, Bhat A, & Srinivasan S (2021). Effects of creative movement therapies on social communication, behavioral-affective, sensorimotor, cognitive, and functional participation skills of individuals with autism spectrum disorder: A systematic review. Frontiers in Psychiatry, 12, 722874. [PubMed: 34867515]

Bal VH, Fok M, Lord C, Smith IM, Mirenda P, Szatmari P, Vaillancourt T, Volden J, Waddell C, Zwaigenbaum L, Bennett T, Duku E, Elsabbagh M, Georgiades S, Ungar WJ, & Zaidman-Zait A (2020). Predictors of longer-term development of expressive language in two independent longitudinal cohorts of language-delayed preschoolers with Autism Spectrum Disorder. Journal of Child Psychology & Psychiatry, 61(7), 826–835. 10.1111/jcpp.13117 [PubMed: 31429087]

Bedford R, Pickles A, & Lord C (2015). Early gross motor skills predict the subsequent development of language in children with autism spectrum disorder. Autism Research, 9(9), 993–1001. 10.1002/aur.1587 [PubMed: 26692550]

Berument SK, Rutter M, Lord C, Pickles A, & Bailey A (1999). Autism screening questionnaire: Diagnostic validity. British Journal of Psychiatry, 175(5), 444–451. 10.1192/bjp.175.5.444

Belmonte M (2022). Motor symptoms in the ASD diagnostic criteria: A conservative perspective. Autism Research, 15(9), 1582–1584. 10.1002/aur.2793 [PubMed: 35968612]

Bhat A (2022). Why add motor to the definition of ASD: A response to Bishop et al.'s critique of Bhat (2021). Autism Research, 15(8), 1376–1379. 10.1002/aur.2776 [PubMed: 35779238]

Bhat A, Su W, Cleffi C, & Srinivasan S (2021). A hybrid clinical trial delivery model in the COVID-19 era. Physical Therapy, 101(8), pzab116. 10.1093/ptj/pzab116 [PubMed: 33909902]

Bhat AN (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. 10.1093/ptj/pzz190 [PubMed: 32154876]

Bhat A (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. [PubMed: 33300285]

Bhat A, Boulton A, & Tulsky D (2022). A further study of relations between motor impairment and social communication, cognitive, language, functional impairments, and repetitive behavior severity in children with ASD using the SPARK study dataset. Autism Research, 15(6), 1156–1178. 10.1002/aur.2711 [PubMed: 35357764]

Bhat AN, Galloway JC, & Landa RJ (2012). Relation between early motor delay and later communication delay in infants at risk for autism. Infant Behavior and Development, 35(4), 838–846. 10.1016/j.infbeh.2012.07.019 [PubMed: 22982285]

Bhat AN, Landa RJ, & Galloway JCC (2011). Current perspectives on motor functioning in infants, children, and adults with autism spectrum disorders. Physical Therapy, 91(7), 1116–1129. 10.2522/ptj.20100294 [PubMed: 21546566]

Bhat AN, Srinivasan SM, Woxholdt C, & Shield A (2018). Differences in praxis performance and receptive language during fingerspelling between deaf children with and without autism spectrum disorder. Autism, 22(3), 271–282. 10.1177/1362361316672179 [PubMed: 29671643]

Bishop SL, Wickstrom J, & Thurm A (2022). Insufficient evidence for inclusion of motor deficits in the ASD diagnostic criteria: A response to Bhat (2021). Autism Research, 15(8), 1374–1375. 10.1002/aur.2775 [PubMed: 35779237]

Biscaldi M, Rauh R, Irion L, Jung NH, Mall V, Fleischhaker C, & Klein C (2014) Deficits in motor abilities and developmental fractionation of imitation performance in high-functioning autism spectrum disorders. Eur Child Adolesc Psychiatry. 23(7), 599–610. [PubMed: 24085467]

Bremer E, & Cairney J (2020). Adaptive behavior moderates health-related pathways in children with autism spectrum disorder. Journal of Autism and Developmental Disorders, 50(2), 491–499. 10.1007/s10803-019-04277-6 [PubMed: 31667652]

Caeyenberghs K, Taymans T, Wilson PH, Vanderstraeten G, Hosseini H, & van Waelvelde H (2016). Neural signature of developmental coordination disorder in the structural connectome independent of comorbid autism. Developmental Science., 19, 599–612. [PubMed: 27147441]

Campos C, Duck M, McQuillan R, Brazill L, Malik S, Hartman L, McPherson AC, Gibson BE, & Jachyra P (2019). Exploring the role of physiotherapists in the care of children with autism spectrum disorder. Physical & Occupational Therapy in Pediatrics, 39(6), 614–628. 10.1080/01942638.2019.1585405 [PubMed: 30957621]

Carter AS, Black DO, Tewani S, Connolly CE, Kadlec M, & Tager-Flusberg H (2007). Sex differences in toddlers with autism spectrum disorders. Journal of Autism & Developmental Disorders, 37, 86–97. 10.1007/s10803-006-0331-7 [PubMed: 17216333]

Choi B, Leech KA, Tager-Flusberg H, & Nelson CA (2018). Development of fine motor skills is associated with expressive language outcomes in infants at high and low risk for autism spectrum disorder. Journal of Neurodevelopmental Disorders, 10(14), 1–11. 10.1186/s11689-018-9231-3 [PubMed: 29329511]

Cleffi C, Su W, Srinivasan S, & Bhat A (2022). Impact of the COVID-19 pandemic on movement intervention research in children with autism spectrum disorder. Pediatric Physical Therapy, 34(2):246–251. [PubMed: 35184077]

Crippa A, Craig F, Busti Ceccarelli S, Mauri M, Grazioli S, Scionti N, Cremascoli A, Ferrante C, Visioli C, Marzocchi GM, Molteni M, & Nobile M (2021). A multimethod approach to assessing motor skills in boys and girls with autism spectrum disorder. Autism. 25(5), 1481–1491. [PubMed: 33653167]

Dahlgren J, Healy S, MacDonald M, Geldhof J, Palmiere K, & Haegele JA (2021). Physical activity and screen time among youth with autism: A longitudinal analysis from 9 to 18 years. Autism. 25(4), 1090–1099. [PubMed: 33406885]

Daniels AM, Rosenberg RE, Anderson C, Law JK, Marvin AR, & Law PA (2011). Verification of parent-report of child autism spectrum disorder diagnosis to a web-based autism registry. Journal of Autism and Developmental Disorders, 42(2), 257–265. 10.1007/s10803-011-1236-7

Dewey D, Cantell M, & Cawford S (2007). Motor and gestural performance in childrenorders, developmental coordination disorder, and/or attention deficit hyperactivity disorder. Journal of the International Neuropsychological Society, 13(2), 246–256. 10.1017/s1355617707070270 [PubMed: 17286882]

Fears NE, Palmer SA, & Miller HL (2021). Motor skills predict adaptive behavior in autistic children and adolescents. Autism Research, 15, 1083–1089.

Feliciano P, Daniels AM, Green Snyder L, Beaumont A, Camba A, Esler A, Gulsrud AG, Mason A, Gutierrez A, Nicholson A, Paolicelli AM, McKenzie AP, Rachubinski AL, Stephens AN, Simon AR, Stedman A, Shocklee AD, Swanson A, Finucane B, … Chung WK (2018). SPARK: A US cohort of 50,000 families to accelerate autism research. Neuron, 97(3), 488–493. 10.1016/j.neuron.2018.01.015 [PubMed: 29420931]

Fleury A, Kushki A, Tanel N, Anagnostou E, & Chau T (2013). Statistical persistence and timing characteristics of repetitive circle drawing in children with ASD. Developmental Neurorehabilitation, 16(4), 245–254. 10.3109/17518423.2012.758184 [PubMed: 23477404]

Fournier KA, Hass CJ, Naik SK, Lodha N, & Cauraugh JH (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. Journal of Autism and Developmental Disorders, 40(10), 1227–1240. 10.1007/s10803-010-0981-3 [PubMed: 20195737]

Gernsbacher MA, Sauer EA, Geye HM, Schweigert EK, & Hill Goldsmith H (2008). Infant and toddler oral- and manual-motor skills predict later speech fluency in autism. Journal of Child Psychology and Psychiatry, 49(1), 43–50. 10.1111/j.1469-7610.2007.01820.X [PubMed: 17979963]

Ghaziuddin M, & Butler E (1998). Clumsiness in autism and Asperger syndrome: a further report. J Intellect Disabil Res. 42(Pt 1), 43–8. [PubMed: 9534114]

Green D, Charman T, Pickles A, Chandler S, Loucas T, Simonoff E, & Baird G (2009). Impairment in movement skills of children with autistic spectrum disorders. Developmental Medicine & Child Neurology, 51(4), 311–316. 10.1111/j.1469-8749.2008.03242.x [PubMed: 19207298]

Gregor S, Bruni N, Grkinic P, Schwartz L, McDonald A, Thille P, Gabison S, Gibson BE, & Jachyra P (2018). Parents' perspectives of physical activity participation among Canadian adolescents with autism spectrum disorder. Research in Autism Spectrum Disorders, 48, 53–62.

Iverson JM, Northrup JB, Leezenbaum NB, Parladé MV, Koterba EA, & West KL (2018). Early communicative and language development in infant siblings of children with autism spectrum disorder. Journal of Autism and Developmental Disorders, 48, 55–71. 10.1007/s10803-017-3297-8 [PubMed: 28900778]

Iverson JM (2018). Early motor and communicative development in infants with an older sibling with autism spectrum disorder. Journal of Speech, Language, and Hearing Research, 61(11), 2673–2684. 10.1044/2018_jslhr-l-rsaut-18-0035

Iverson JM (2021). Developmental variability and developmental cascades: Lessons from motor and language development in infancy. Current Directions in Psychological Science, 30(3), 228–235. 10.1177/0963721421993822 [PubMed: 34194130]

Jachyra P, Renwick R, Gladstone B, Anagnostou E, & Gibson BE (2021). Physical activity participation among adolescents with autism spectrum disorder. Autism., 25(3), 613–626. [PubMed: 32921151]

Jansiewicz EM, Goldberg MC, Newschaffer CJ, Denckla MB, Landa R, & Mostofsky SH (2006). Motor signs distinguish children with high functioning autism and Asperger's syndrome from controls. Journal of Autism and Developmental Disorders, 36(5), 613–621. 10.1007/s10803-006-0109-y [PubMed: 16609826]

Jasmin E, Couture M, McKinley P, Reid G, Fombonne E, & Gisel E (2009). Sensori-motor and daily living skills of preschool children with autism spectrum disorders. Journal of Autism and Developmental Disorders, 39(2), 231–241. 10.1007/s10803-008-0617-z [PubMed: 18629623]

Kaur M, Eigsti I-M, & Bhat A (2021). Effects of creative yoga intervention on the joint attention, social communication, and affective states of children with autism spectrum disorder. Research in Autism Spectrum Disorders, 88, 101860. 10.1016/j.rasd.2021.101860 [PubMed: 34552663]

Kaur M, & Bhat A (2019). Creative yoga intervention improves motor and imitation skills of children with autism spectrum disorder. Physical Therapy, 99(11), 1520–1534. 10.1093/ptj/pzz115 [PubMed: 31765484]

Kaur M, Srinivasan S, & Bhat A (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. 10.1016/j.ridd.2017.10.025 [PubMed: 29121516]

Kaur M, Srinivasan S, & Bhat A (2015). Atypical object exploration skills in infants at-risk for autism during the first year of life. Frontiers in Psychology, 6, 1–15. (Special edition on goal-directed social and object interactions in infancy). 10.3389/fpsyg.2015.00798 [PubMed: 25688217]

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. 10.1177/1362361316650611 [PubMed: 27354429]

Ketcheson LR, Pitchford EA, & Wentz CF (2021). The relationship between developmental coordination disorder and concurrent deficits in social communication and repetitive behaviors among children with autism spectrum disorder. Autism Research, 14(4), 804–816. Epub 2021 Jan 9. 10.1002/aur.2469 [PubMed: 33421296]

Kilroy E, Ring P, Hossain A, Nalbach A, Butera C, Harrison L, Jayashankar A, Vigen C, Aziz-Zadeh L, & Cermak S (2022). Motor performance, praxis, and social skills in autism spectrum disorder and developmental coordination disorder. Autism Research. 15(9):1649–1664. 10.1002/aur.2774 [PubMed: 35785418]

Kirby A, Edwards L, Sugden D, & Rosenblum S (2010). The development and standardization of the Adult Developmental Coordination Disorders/Dyspraxia Checklist (ADC). Research in Developmental Disabilities, 31(1), 131–139. 10.1016/j.ridd.2009.08.010 [PubMed: 19819107]

Kopp S, Beckung E, & Gillberg C (2010). Developmental coordination disorder and other motor control problems in girls with autism spectrum disorder and/or attention deficit/hyperactivity disorder. Research in Developmental Disabilities, 31(2), 350–361. 10.1016/j.ridd.2009.09.017 [PubMed: 19910158]

Kushki A, Chau T, & Anagnostou E (2011). Handwriting difficulties in children with autism spectrum disorders: A scoping review. Journal of Autism and Developmental Disorders, 41(12), 1706–1716. 10.1007/s10803-011-1206-0 [PubMed: 21350917]

Lam KSL, & Aman MG (2006). The repetitive behavior scale-revised: Independent validation in individuals with autism spectrum disorders. Journal of Autism and Developmental Disorders, 37(5), 855–866. 10.1007/s10803-006-0213-z

LeBarton ES, & Landa RJ (2019). Infant motor skill predicts later expressive language and autism spectrum disorder diagnosis. Infant Behavior and Development, 54, 37–47. 10.1016/j.infbeh.2018.11.003 [PubMed: 30557704]

Lee H, Marvin AR, Watson T, Piggot J, Law JK, Law PA, Constantino JN, & Nelson SF (2010). Accuracy of phenotyping of autistic children based on internet implemented parent report. American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 153B, 1119–1126. 10.1002/ajmg.b.31103

Leezenbaum N, Campbell S, Butler D, & Iverson J (2014). Maternal verbal responses to communication of infants at low and heightened risk of autism. Autism., 18(6), 694–703. 10.1177/1362361313491327 [PubMed: 24113343]

Licari MK, Alvares GA, Varcin K, Evans KL, Cleary D, Reid SL, Glasson EJ, Bebbington K, Reynolds JE, Wray J, & Whitehouse AJO (2020). Prevalence of motor difficulties in autism spectrum disorder: Analysis of a population-based cohort. Autism Research, 13(2), 298–306. 10.1002/aur.2230 [PubMed: 31625694]

Licari MK, Alvares GA, Reynolds JE, & Uljaveric M (2022). Motor impairment should be a “Specifier” for autism spectrum disorder. Autism Res. 15(11), 2010–2011. [PubMed: 36129385]

Lloyd M, MacDonald M, & Lord C (2013). Motor skills of toddlers with autism spectrum disorders. Autism, 17(2), 133–146. 10.1177/1362361311402230 [PubMed: 21610184]

MacDonald M, Lord C, & Ulrich D (2013). The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. Research in Autism Spectrum Disorders, 7(11), 1383–1390. 10.1016/j.rasd.2013.07.020 [PubMed: 25774214]

MacDonald M, Lord C, & Ulrich D (2014). Motor skills and calibrated autism severity in young children with autism spectrum disorder. Adapted Physical Activity Quarterly, 31(2), 95–105. 10.1123/apaq.2013-0068 [PubMed: 24762385]

MacNeil LK, & Mostofsky SH (2012). Specificity of dyspraxia in children with autism. Neuropsychology, 26(2), 165–171. 10.1037/a0026955 [PubMed: 22288405]

Maenner MJ, Shaw KA, Bakian AV, Bilder DA, Durkin MS, Esler A, Furnier SM, Hallas L, Hall-Lande J, Hudson A, Hughes MM, Patrick M, Pierce K, Poynter JN, Salinas A, Shenouda J, Vehorn A, Warren Z, Constantino JN, … Cogswell ME (2021). Prevalence of autism spectrum disorder among children aged 8 years—Autism and developmental disabilities monitoring network, 11 sites, United States, 2018. Morbidity and Mortality Weekly Report - Surveillance Summaries, 70(11), 1–16.

Mari M, Castiello U, Marks D, Marraffa C, & Prior M (2003). The reach-to-grasp movement in children with autism spectrum disorder. Philos Trans R Soc Lond B Biol Sci. 358(1430), 393–403. [PubMed: 12639336]

Marvin AR, Marvin DJ, Lipkin PH, & Law JK (2017). Analysis of Social Communication Questionnaire (SCQ) screening for children less than age 4. Current Developmental Disorders Reports, 4(4), 137–144. 10.1007/s40474-017-0122-1 [PubMed: 29188169]

Maximo J, Cadena E, & Kana R (2014). The implications of brain connectivity in the neuropsychology of autism. Neuropsychology Reviews, 24(1), 16–31. 10.1007/s11065-014-9250-0

McPhillips M, Finlay J, Bejerot S, & Hanley M (2014). Motor deficits in children with autism spectrum disorder: A cross-syndrome study. Autism Research, 7(6), 664–676. 10.1002/aur.1408 [PubMed: 25258309]

Miller HL, Sherrod GM, Mauk JE, Fears NE, Hynan LS, & Tamplain P (2021). Shared features or co-occurrence? Evaluating symptoms of developmental coordination disorder in children and adolescents with autism spectrum disorder. Journal of Autism and Developmental Disorders, 51(10), 3443–3455. 10.1007/s10803-020-04766-z [PubMed: 33387238]

Monz BU, Houghton R, Law K, & Loss G (2019). Treatment patterns in children with autism in the United States. Autism Res. 12(3), 517–526. [PubMed: 30629336]

Nakai A, Miyachi T, Okada R, Tani I, Nakajima S, Onishi M, Fujita C, & Tsujii M (2011). Evaluation of the Japanese version of the Developmental Coordination Disorder Questionnaire as a screening tool for clumsiness of Japanese children. Res Dev Disabil. 32(5), 1615–22. [PubMed: 21377832]

Nebel MB, Eloyan A, Nettles CA, Sweeney KL, Ament K, Ward RE, Choe AS, Barber AD, Pekar JJ, & Mostofsky SH (2016). Intrinsic visual-motor synchrony correlates with social deficits in autism. Biological Psychiatry, 79(8), 633–641. 10.1016/j.biopsych.2015.08.029 [PubMed: 26543004]

Radonovich K, Fournier K, & Hass C (2013). Relationship between postural control and restricted, repetitive behaviors in autism spectrum disorders. Frontiers in Integrative Neuroscience., 7(7), 28. 10.3389/fnint.2013.00028.eCollection2013 [PubMed: 23675326]

Ravizza SM, Solomon M, Ivry RB, & Carter CS (2013). Restricted and repetitive behaviors in autism spectrum disorders: The relationship of attention and motor deficits. Developmental Psychopathology, 25(3), 773–784. 10.1017/S0954579413000163

Rosen NE, Lord C, & Volkmar FR (2021). The diagnosis of autism: From Kanner to DSM-III to DSM-5 and beyond. Journal of Autism and Developmental Disorders, 51(12), 4253–4270. 10.1007/s10803-021-04904-1 [PubMed: 33624215]

Schoemaker MM, Flapper B, Verheij NP, Wilson BN, Reinders-Messelink HA, & de Kloet A (2006). Evaluation of the developmental coordination disorder questionnaire as a screening instrument. Developmental Medicine & Child Neurology, 48(8), 668. 10.1017/s001216220600140x [PubMed: 16836779]

Shield A, Knapke K, Henry M, Srinivasan S, & Bhat A (2017). Impaired praxis in gesture imitation by deaf children with autism spectrum disorder. Autism & Developmental Language Impairments, 2, 239694151774567. 10.1177/2396941517745674

Sumner E, Leonard HC, & Hill EL (2016). Overlapping phenotypes in autism spectrum disorder and developmental coordination disorder: A cross-syndrome comparison of motor and social skills. Journal of Autism & Developmental Disorders., 46, 2609–2620. 10.1007/s10803-016-2794-5 [PubMed: 27126816]

Srinivasan SM, & Bhat AN (2013). A review of “music and movement” therapies for children with autism: Embodied interventions for multisystem development. Frontiers in Integrative Neuroscience, 7(Article 22), 1–22. 10.3389/fnint.2013.00022 [PubMed: 23355815]

Srinivasan SM, & Bhat AN (2016). Differences in object sharing between infants at risk for autism and typically developing infants from 9 to 15 months of age. Infant Behavior and Development, 42, 128–141. 10.1016/j.infbeh.2015.12.003 [PubMed: 26803417]

Srinivasan S, & Bhat A (2019). Differences in means-end exploration between infants at risk for autism and typically developing infants in the first 15 months of life. Developmental Psychobiology, 61(2), 203–215. 10.1002/dev.21810 [PubMed: 30511480]

Srinivasan S, & Bhat A (2020). Differences in caregiver behaviors of infants at-risk for autism and typically developing infants from 9 to 15 months of age. Infant Behavior and Development, 59, 101445. 10.1016/j.infbeh.2020.101445 [PubMed: 32305735]

Srinivasan SM, Eigsti I-M, Gifford T, & Bhat AN (2016). The effects of embodied rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorder (ASD): A further outcome of a pilot randomized controlled trial. Research in Autism Spectrum Disorders, 27, 73–87. 10.1016/j.rasd.2016.04.001 [PubMed: 27668011]

Srinivasan SM, Eigsti I-M, Neelly L, & Bhat AN (2016). The effects of embodied rhythm and robotic interventions on the spontaneous and responsive social attention patterns of children with autism

spectrum disorder (ASD): A pilot randomized controlled trial. Research in Autism Spectrum Disorders, 27, 54–72. 10.1016/j.rasd.2016.01.004 [PubMed: 27453721]

Srinivasan SM, Kaur M, Park IK, Gifford TD, Marsh KL, & Bhat AN (2015). The effects of rhythm and robotic interventions on the imitation/praxis, interpersonal synchrony, and motor performance of children with autism spectrum disorder (ASD): A pilot randomized controlled trial. Autism Research and Treatment, 2015 (ID: 736516)1–18. 10.1155/2015/736516

Srinivasan SM, Park IK, Neelly LB, & Bhat AN (2015). A comparison of the effects of rhythm and robotic interventions on repetitive behaviors and affective states of children with Autism Spectrum Disorder (ASD). Research in Autism Spectrum Disorders, 18, 51–63. 10.1016/j.rasd.2015.07.004 [PubMed: 26251668]

Srinivasan SM, Pescatello LS, & Bhat AN (2014). Current perspectives on physical activity and exercise recommendations for children and adolescents with autism spectrum disorders. Physical Therapy, 94(6), 875–889. 10.2522/ptj.20130157 [PubMed: 24525861]

Srinivasan S, Su W, Cleffi C, & Bhat A (2021). From social distancing to social connections: Insights from the delivery of a clinician-caregiver co-mediated telehealth-based intervention in children with autism spectrum disorder. Frontiers in Psychiatry, 12, 700247. 10.3389/fpsyt.2021.700247 [PubMed: 34276452]

Staples K, & Reid G (2010). Fundamental movement skills and autism spectrum disorders. Journal of Autism and Developmental Disorders, 40(2), 209–217. 10.1007/s10803-009-0854-9 [PubMed: 19685284]

Uljarević M, Jo B, Frazier TW, Scahill L, Youngstrom EA, & Hardan AY (2021). Using the big data approach to clarify the structure of restricted and repetitive behaviors across the most commonly used autism spectrum disorder measures. Molecular Autism, 12(1), 39. 10.1186/s13229-021-00419-9 [PubMed: 34044873]

Van Damme T, Vancampfort D, Thoen A, Sanchez C, & Van Biesen D (2022). Evaluation of the Developmental Coordination Questionnaire (DCDQ) as a screening instrument for co-occurring motor problems in children with autism spectrum disorder. Journal of Autism and Developmental Disorders, 52, 4079–4088. 10.1007/s10803-021-05285-1 [PubMed: 34535846]

Van Waelvelde H, Oostra A, Dewitte G, Van Den Broek C, & Jongmans M (2010). Stability of motor problems in young children with or at risk of autism spectrum disorders, ADHD, and or developmental coordination disorder. Developmental Medicine & Child Neurology, 52(8), e174–e178. [PubMed: 20132135]

Vasa RA, Mostofsky SH, & Ewen JB (2016). The disrupted connectivity hypothesis of autism spectrum disorders: Time for the next phase in research. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 1(3), 245–252. 10.1016/j.bpsc.2016.02.003 [PubMed: 28083565]

Wang LAL, Petrulla V, Zampella CJ, Waller R, & Schultz RT (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. 10.1037/bul0000358 [PubMed: 35511567]

Wilson BN, Crawford SG, Green D, Roberts G, Aylott A, & Kaplan B (2009). Psychometric properties of the revised Developmental Coordination Disorder Questionnaire. Physical & Occupational Therapy in Pediatrics, 29(2), 182–202. 10.1080/01942630902784761 [PubMed: 19401931]

Wilson BN, Creighton D, Crawford SG, Heath JA, Semple L, Tan B, & Hansen S (2015). Psychometric properties of the canadian little developmental coordination disorder questionnaire for preschool children. Physical & Occupational Therapy in Pediatrics, 35(2), 116–131. 10.3109/01942638.2014.980928 [PubMed: 25456610]

Zwaigenbaum L, Bauman ML, Stone WL, Yirmiya N, Estes A, Hansen RL, McPartland JC, Natowicz MR, Choueiri R, Fein D, Kasari C, Pierce K, Buie T, Carter A, Davis PA, Granpeesheh D, Mailloux Z, Newschaffer C, Robins D, … Wetherby A (2015). Early identification of autism spectrum disorder: Recommendations for practice and research. Pediatrics, 136(Suppl.), S10–S40. 10.1542/peds.2014-3667c [PubMed: 26430168]

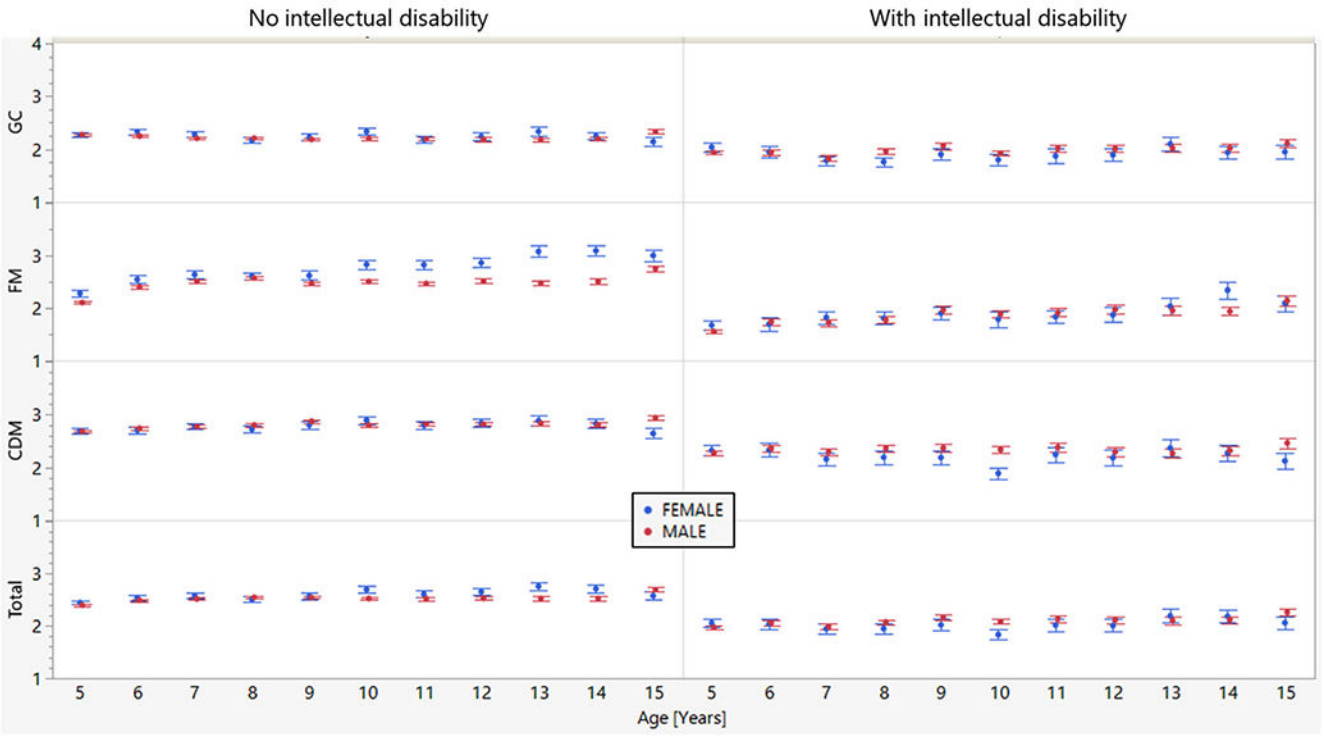

FIGURE 1.

Normalized Developmental Coordination Disorder-Questionnaire (DCD-Q) scores (total, CDM, control during movement; FM, fine motor; GC, general coordination) versus age, sex, and presence of intellectual disability. A score of 1 is poor performance/not at all like the stated skill and 5 is best performance/extremely similar to the stated skill.

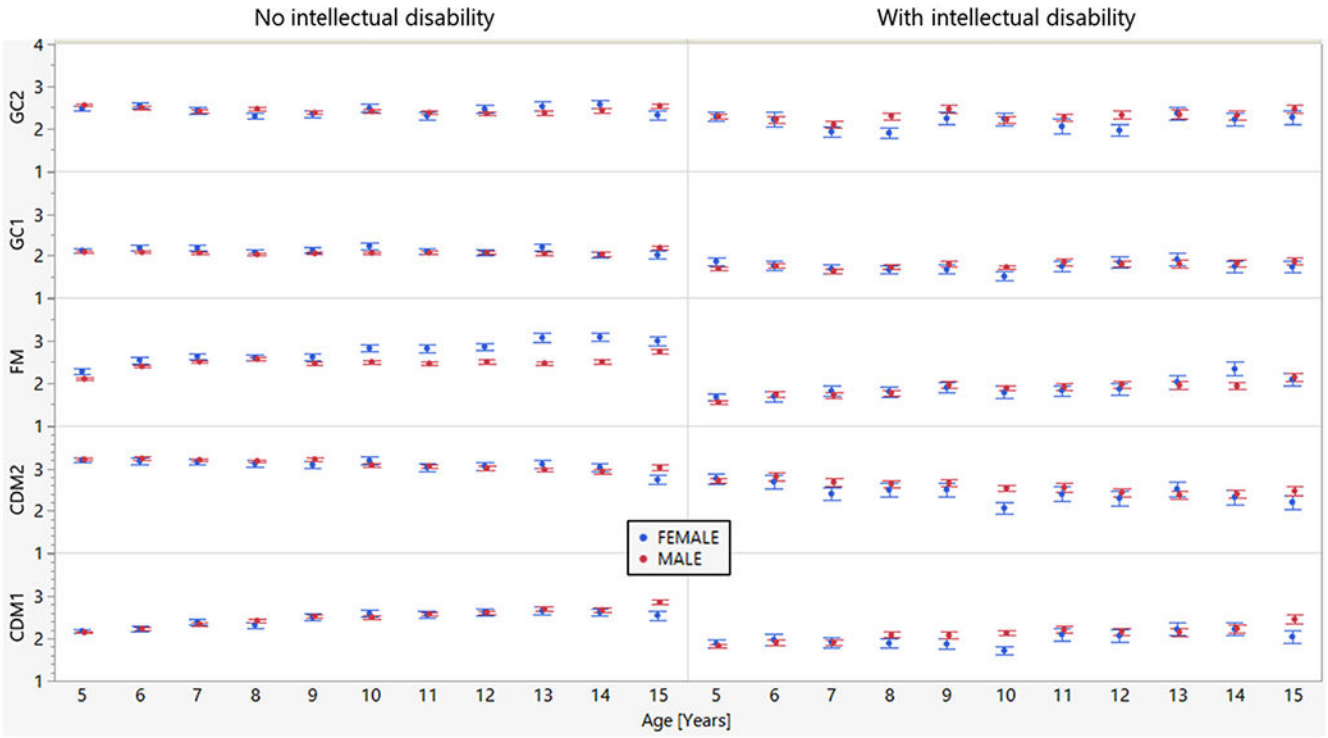

FIGURE 2.

Normalized Developmental Coordination Disorder-Questionnaire (DCD-Q) sub-domain scores (CDM1, control during movement 1; CDM2, control during movement 2; FM, fine motor; GC1, general coordination 1; GC2, general coordination 2) versus age, sex, and presence of intellectual disability. A score of 1 is poor performance/not at all like the stated skill and 5 is best performance/extremely similar to the stated skill.

TABLE 1

Items subdivided into standard DCD-Q subdomains and factor analysis (FA)-based subdomains

	Standard/original subdomains			FA-based subdomains FM = Same as standard/original				
DCD-Q Items	**CDM**	**FM**	**GC**	**CDM1**	**CDM2**	**FM**	**GC1**	**GC2**
1. Throws ball								
2. Catches ball								
3. Hits ball/birdie								
4. Jumps over								
5. Runs								
6. Plans activity								
7. Writing fast								
8. Writing legibly								
9. Writing effort/pressure								
10. Cuts								
11. Likes sports								
12. Learns new skills								
13. Quick/competent								
14. Never described as a “bull in a shop”								
15. Does not fatigue easily								

Note: Shading within cells indicate that the item in the row belongs to the DCD-Q factor/subscale stated in the column header. The normalized scores in this work are obtained by dividing the total for each domain by the number of items considered within the domain. This allows comparison of performance across domains. A score of 1 is poor performance/not at all like the stated skill and 5 is best performance/extremely similar to the stated skill.

Abbreviations: CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination.

TABLE 2

F values from a three-way ANOVA on effects of age, sex, and intellectual disability

Three-way ANOVA effects on DCD-Q scores based on age, sex, and intellectual disability factors							
DCD score type	**Age**	**Sex**	**ID**	**Age × sex interaction**	**Age × ID interaction**	**Sex × ID interaction**	**Age × sex × ID interaction**
Total (Q01–Q15)	28.90		545.10				
CDM (Q01–Q06)			382.96				
FM (Q07–Q10)	146.98	23.70	637.75		13.42		
GC (Q11–Q15)			173.34				
CDM1 (Q01–Q03)	136.04		240.11				
CDM2 (Q04–Q06)	57.22		369.09				
GC1 (Q11–Q13)			199.34				
GC2 (Q14–Q15)			49.49				

Note: $p < 0.0009$. Blank cells indicate that the *F* values were not significant.

Abbreviations: ANOVA, analysis of variance; CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination; ID, intellectual disability.

TABLE 3

Means, SDs, and SEs of the DCD-Q total and sub-domain scores by age, sex, and presence of intellectual disability (ID)

Means

Age level	**5–8 Years**				**9–12 Years**				**13–15 Years**			
Sex	**Male**		**Female**		**Male**		**Female**		**Male**		**Female**	
ID	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
DCD score type												
Total (Q01–Q15)	37.10	30.23	37.60	30.09	37.92	31.81	39.31	29.52	38.57	32.35	40.21	32.17
CDM (Q01–Q06)	16.46	13.91	16.33	13.59	16.99	14.08	16.99	12.76	17.15	14.08	16.74	13.55
FM (Q07–Q10)	9.44	6.70	9.93	6.95	9.96	7.73	11.10	7.41	10.26	8.03	12.25	8.63
GC (Q11–Q15)	11.21	9.61	11.34	9.55	10.97	10.00	11.22	9.34	11.16	10.24	11.22	9.99
CDM1 (Q01–Q03)	6.80	5.76	6.80	5.72	7.66	6.43	7.70	5.80	8.21	6.83	7.83	6.49
CDM2 (Q04–Q06)	9.66	8.15	9.54	7.86	9.33	7.65	9.29	6.96	8.95	7.25	8.91	7.06
GC1 (Q11–Q13)	6.21	5.11	6.43	5.30	6.20	5.36	6.41	5.08	6.25	5.49	6.24	5.40
GC2 (Q14–Q15)	4.99	4.50	4.91	4.25	4.77	4.64	4.81	4.27	4.90	4.75	4.97	4.59

SDs

Age level	**5–8 Years**				**9–12 Years**				**13–15 Years**			
Sex	**Male**		**Female**		**Male**		**Female**		**Male**		**Female**	
ID	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
DCD score type												
Total (Q01–Q15)	9.98	12.05	10.45	12.19	11.44	12.32	11.21	13.07	11.95	12.81	12.43	9.98
CDM (Q01–Q06)	5.39	5.54	5.48	6.00	5.75	5.82	5.52	6.47	6.01	6.12	6.04	5.39
FM (Q07–Q10)	3.37	4.51	3.44	4.36	3.93	4.50	3.64	4.51	3.97	4.76	4.33	3.37
GC (Q11–Q15)	3.63	4.29	3.66	4.30	3.98	4.29	3.83	4.55	4.20	4.38	4.23	3.63
CDM1 (Q01–Q03)	2.58	2.85	2.64	3.28	3.06	3.16	2.71	3.51	3.30	3.21	3.01	2.58
CDM2 (Q04–Q06)	3.58	3.41	3.47	3.41	3.44	3.38	3.37	3.53	3.30	3.51	3.55	3.58
GC1 (Q11–Q13)	2.32	2.84	2.45	2.87	2.50	2.86	2.50	2.98	2.76	2.89	2.87	2.32
GC2 (Q14–Q15)	2.26	2.31	2.16	2.27	2.31	2.26	2.11	2.31	2.32	2.34	2.06	2.26

SEs

Age level	**5–8 Years**	**9–12 Years**	**13–15 Years**

Means												
Age level	**5–8 Years**				**9–12 Years**				**13–15 Years**			
Sex	**Male**		**Female**		**Male**		**Female**		**Male**		**Female**	
ID	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Sex	**Male**		**Female**		**Male**		**Female**		**Male**		**Female**	
ID	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
DCD score type												
Total (Q01–Q15)	0.17	0.33	0.36	0.66	0.22	0.44	0.48	0.82	0.33	0.60	0.66	1.06
CDM (Q01–Q06)	0.08	0.18	0.17	0.35	0.11	0.22	0.23	0.40	0.16	0.30	0.31	0.51
FM (Q07–Q10)	0.07	0.11	0.14	0.22	0.08	0.15	0.17	0.27	0.11	0.20	0.24	0.37
GC (Q11–Q15)	0.06	0.12	0.13	0.23	0.08	0.15	0.17	0.28	0.11	0.21	0.22	0.36
CDM1 (Q01–Q03)	0.04	0.08	0.09	0.17	0.06	0.12	0.12	0.20	0.09	0.17	0.16	0.26
CDM2 (Q04–Q06)	0.05	0.12	0.10	0.22	0.06	0.13	0.13	0.25	0.09	0.17	0.18	0.30
GC1 (Q11–Q13)	0.04	0.08	0.09	0.16	0.05	0.10	0.11	0.18	0.07	0.14	0.15	0.24
GC2 (Q14–Q15)	0.03	0.07	0.07	0.14	0.04	0.09	0.09	0.15	0.06	0.12	0.12	0.18

Abbreviations: CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination.

TABLE 4

Scores based on the percentile distribution of normalized DCD-Q scores for the whole SPARK sample included in this study

DCD score type	0%	10%	25%	50%	75%	90%	100%
Total (Q01–Q15)/15	1.00	1.47	1.80	2.33	3.00	3.60	5.00
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.33	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.60	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.00	3.00	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.50	3.00	4.00	5.00

Note: The normalized scores allow comparison between subdomains with 1 indicating poor performance/not at all like the stated skill, 3 being moderately similar to the stated skill, and 5 being extremely similar to the stated skill.

Abbreviations: CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination.

TABLE 5

DCD-Q scores based on the percentile distribution of the sample for normalized DCD-Q scores calculated for each age group

Age: 5 years to 5 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.40	1.73	2.20	2.80	3.40	5.00
CDM (Q01–Q06)/6	1.00	1.50	1.83	2.50	3.17	3.83	5.00
FM (Q07–Q10)/4	1.00	1.00	1.25	1.75	2.75	3.75	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.20	2.80	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.33	2.00	2.67	3.33	5.00
CDM2 (Q04–Q06)/3	1.00	1.67	2.33	3.33	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.50	3.50	4.00	5.00
Age: 6 years to 6 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.87	2.33	2.93	3.47	4.80
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.33	4.00	5.00
FM (Q07–Q10)/4	1.00	1.00	1.25	2.00	3.00	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.20	2.80	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.33	2.00	2.67	3.67	5.00
CDM2 (Q04–Q06)/3	1.00	1.67	2.33	3.33	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	2.00	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.50	3.00	4.00	5.00
Age: 7 years to 7 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.80	2.33	3.00	3.60	4.93
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.50	4.00	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.60	3.24	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.33	2.00	3.00	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.67	2.00	3.00	4.00	4.67	5.00

Age: 5 years to 5 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 8 years to 8 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.87	2.33	2.93	3.53	5.00
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.33	4.00	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.60	3.20	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.00	3.00	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.42	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 9 years to 9 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.80	2.40	3.07	3.60	4.93
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.50	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.60	3.40	4.80
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.33	3.00	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.67	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 10 years to 10 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.41	1.80	2.40	3.00	3.60	4.73
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.46	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.40	2.00	2.60	3.40	4.80
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.33	3.00	4.00	5.00

Age: 5 years to 5 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 11 years to 11 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.80	2.40	3.07	3.60	4.93
CDM (Q01–Q06)/6	1.00	1.50	2.00	2.67	3.50	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.00	5.00
GC (Q11–Q15)/5	1.00	1.20	1.40	2.00	2.80	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.33	1.67	2.33	3.33	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 12 years to 12 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.80	2.33	3.00	3.61	5.00
CDM (Q01–Q06)/6	1.00	1.47	1.83	2.67	3.50	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.05	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.60	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.33	3.33	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	3.67	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 13 years to 13 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.40	1.80	2.40	3.07	3.73	5.00
CDM (Q01–Q06)/6	1.00	1.33	1.83	2.67	3.50	4.33	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.25	5.00
GC (Q11–Q15)/5	1.00	1.20	1.40	2.00	2.80	3.60	5.00

Age: 5 years to 5 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.33	3.33	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	3.00	4.00	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.00	3.00	4.00	5.00
Age: 14 years to 14 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.40	1.80	2.33	3.13	3.67	5.00
CDM (Q01–Q06)/6	1.00	1.33	1.83	2.67	3.50	4.17	5.00
FM (Q07–Q10)/4	1.00	1.00	1.50	2.25	3.25	4.25	5.00
GC (Q11–Q15)/5	1.00	1.20	1.40	2.00	2.60	3.40	5.00
CDM1 (Q01–Q03)/3	1.00	1.00	1.67	2.33	3.33	4.00	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	2.00	2.67	3.67	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.33	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.50	3.00	4.00	5.00
Age: 15 years to 15 years and 11 months							
DCD score type	**0%**	**10%**	**25%**	**50%**	**75%**	**90%**	**100%**
Total (Q01–Q15)/15	1.00	1.47	1.87	2.47	3.20	3.87	5.00
CDM (Q01–Q06)/6	1.00	1.50	1.83	2.67	3.67	4.50	5.00
FM (Q07–Q10)/4	1.00	1.25	1.75	2.50	3.50	4.50	5.00
GC (Q11–Q15)/5	1.00	1.20	1.60	2.00	2.80	3.60	5.00
CDM1 (Q01–Q03)/3	1.00	1.33	1.67	2.33	3.67	4.67	5.00
CDM2 (Q04–Q06)/3	1.00	1.33	1.67	2.67	3.67	4.67	5.00
GC1 (Q11–Q13)/3	1.00	1.00	1.33	1.67	2.67	3.67	5.00
GC2 (Q14–Q15)/2	1.00	1.00	1.50	2.50	3.50	4.00	5.00

Note: The normalized scores allow comparison between subdomains with 1 indicating poor performance/child not at all performing similar to the stated skill, 3 indicating performance moderately similar to the stated skill, and 5 being performance extremely similar to the stated skill. Note the stability in subdomain scores with increasing age. Scores for children in the 50th and 75th percentile are highlighted and discussed in the results.

Abbreviations: CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination.

TABLE 6

Pearson correlations of DCD-Q score with age, and Spearman correlations of DCD-Q scores with sex and presence of intellectual disability (ID)

DCD score type	Age	Sex	ID
Total (Q01–Q15)	0.06		−0.22
CDM (Q01–Q06)	0.04		−0.19
FM (Q07–Q10)	0.12	0.06	−0.24
GC (Q11–Q15)			−0.13
CDM1 (Q01–Q03)	0.17		−0.15
CDM2 (Q04–Q06)	−0.09		−0.19
GC1 (Q11–Q13)			−0.15
GC2 (Q14–Q15)			−0.06

Note: p values <0.0001.

Abbreviations: CDM, control during movement; DCD-Q, Developmental Coordination Disorder-Questionnaire; FM, fine motor; GC, general coordination.

TABLE 7

Wald chi-square statistic to predict the impairment categories based on SCI and RB severity as well as language and functional delay using age, sex, presence of intellectual disability, and DCD-Q total/subdomain/item scores within ordinal logistic regression analyses

DCD score type	SCI category	RB category	Language delay category	Functional delay category
N	13,887	13,803	13,423	13,449
Predictions using age, sex, intellectual disability, and total DCD-Q score				
Age	325.7**	69.3**	877.8**	
Sex	5.0*			5.6*
Intellectual disability	140.1**	39.3**	924.1**	366.7**
Total (Q01–Q15)	1149.2**	828.5**	440.5**	2150.7**
Predictions using age, sex, intellectual disability, and the standard subdomains				
Age	333.7**	66.7**	712.3**	
Sex	4.9*			10.5**
Intellectual disability	129.2**	40.7**	785.5**	330.1**
CDM (Q01–Q06)	233.5**		239.7**	197.4**
FM (Q07–Q10)	147.1**	180.8**	636.9**	593.5**
GC (Q11–Q15)	32.7**	212.3**	320.4**	129.6**
Predictions using age, sex, intellectual disability, and FA-based subdomains				
Age	329.7**	64.9**	622.2**	
Sex	4.4*			13.0**
Intellectual disability	130.3**	40.5**	790.0**	331.4**
CDM1 (Q01–Q03)	89.8**		98.7**	13.9**
CDM2 (Q04–Q06)	39.8**	5.8*	36.5**	58.3**
FM (Q07–Q10)	140.8**	187.7**	623.5**	547.0**
GC1 (Q11–Q13)	40.0**	30.4**	67.9**	285.8**
GC2 (Q14–Q15)		167.7**	214.1**	4.3*

DCD score type	SCI category	RB category	Language delay category	Functional delay category
Predictions using age, sex, intellectual disability, and DCD-Q questions (items)				
Age	348.6**	24.9**	464.8**	13.6**
Sex	5.9*			10.2**
Intellectual disability	112.1**	39.9**	700.8**	289.8**
Q01. Throws ball		31.2**	10.2**	8.9*
Q02. Catches ball		23.0**	8.0*	
Q03. Hits a ball/birdie	45.5**	4.1*	100.3**	10.8**
Q04. Jumps		8.8*	13.5**	
Q05. Runs			30.0**	
Q06. Plans	101.5**		365.7**	147.9**
Q07. Writes fast	22.4**		88.5**	31.9**
Q08. Writes legibly	11.4**	21.4**	7.1*	11.0**
Q09. Writing effort/pressure	34.9**	177.8**		
Q10. Cuts	7.4*		156.0**	93.0**
Q11. Likes sports	25.0**			9.3**
Q12. Learns new skills			17.3**	
Q13. Quick/competent	26.6**	101.4**	74.1**	518.5**
Q14. Never described as a “bull in a china shop”	8.3*	63.5**	4.1*	
Q15. Does not fatigue easily		34.9**	151.7**	9.2**

Note: Predictor significance is based on FDR-corrected *p* values. Green highlighted cells show motor subdomains that were significantly predicting other system domains. Abbreviations: CDM, control during movement; FM, fine motor; GC, general coordination; DCD-Q, Developmental Coordination Disorder-Questionnaire; FDR, false discovery rate; RB, repetitive behaviors; SCI, social communication impairment.

** $p < 0.05$/number of independent factors;

* $p < 0.05$.