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Relationships between autistic traits, motor skills and socioeconomic status☆

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ABSTRACT

Background: Autism is a neurodevelopmental condition that presents with social and communicative difficulties as well as restricted or repetitive behaviors. Previous research has highlighted the ubiquity of motor impairments in autistic children, but the relationship between the severity of motor impairment and the degree of autistic traits has not yet been adequately researched. The role of socioeconomic status in the development of autism is also poorly understood.
Method: We used the Autism Treatment Evaluation Checklist (ATEC) to assess social and behavioral autistic traits and the Bruininks-Oseretsky Motor Proficiency Test (Second Edition) to assess motor skills in a cohort of 50 children from the central Johannesburg region. A short questionnaire was used to assess socioeconomic status of the family of each participant.
Results: Significant correlations were found between many motor skill domains and the domains of the ATEC specifically pertaining to sociability, communication and sensory awareness ($p < 0.05$), but no relationships between autistic traits and socioeconomic status were observed.
Conclusions: Our findings support a possible relationship in the aetiology of social and communicative autistic traits, and impairment of motor skills. Therefore, motor interventions could potentially be used to improve social and communicative difficulties, as well as perseverative behaviors in autism.

Autism is a neurodevelopmental condition characterized by challenges in communication and sociability as well as restricted interests and repetitive behaviors (American Psychological Association, 2013). While behavioral traits are used to identify autism, autistic individuals also commonly present with sensory dysregulation and motor impairment (Miller et al., 2014). The ubiquity of motor impairment observed in autism raises the question of a shared etiology between the development of motor skills and the development of social and communicative behaviors. Additionally, the role played by socioeconomic status (SES) in the development

☆ The autism-specific language used in this article has followed the recommendations of (Monk et al., 2022), and follows an identity-first format as per recommendations to reduce disorder-focused language and subsequent stigmatization.

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of autism is complex and poorly understood.

Importantly, a wide range of motor impairments have been documented in autism (Berkeley et al., 2001; Bhat et al., 2018; Dowell et al., 2009; Freitag et al., 2007; Hallett et al., 1993; Jansiewicz et al., 2006; Minshew et al., 2004; Mostofsky et al., 2006; Rinehart et al., 2006; Teitelbaum et al., 1998; Vilensky et al., 1981), with some authors suggesting that motor impairment may be a central feature of the condition (Bhat et al., 2011; Fournier et al., 2010) and an element that should be screened for early on in the autism diagnostic process (Miller et al., 2023). Previous research has investigated the relationship between motor impairment and autistic traits. In deaf autistic children, poorer receptive language has been found to correlate with poorer praxis and more severe autism traits (Bhat et al., 2018), which is indicative of potential relationships between motor processing, communicative processing and autistic characteristics. In very young children (aged 14 – 33 months), weaker fine and gross motor skills have been found to predict severity of social and communicative autism traits (MacDonald et al., 2014). Degree of motor impairment in autistic children has also been found to associate with the degree of social withdrawal exhibited (Freitag et al., 2007). Hilton et al. (2012) used the BOT-2 to assess motor impairment in sibling pairs in which one sibling had autism and one did not. They found significant associations between motor impairment and autistic traits by group. Furthermore, severity of autism characteristics have been found to relate to decreased postural stability in adolescents and adults (Travers et al., 2013), and impairment in motor skills has been found to relate to decreased adaptive behaviours and impairment in daily living skills in autistic children (MacDonald et al., 2013). A more recent systematic review of the literature concluded that 50–88% of autistic children are likely to have significant motor impairment (Kangarani-Farahani et al., 2023). The results of this body of research indicate a high likelihood that severity of motor impairment and degree of autistic traits are closely linked, although there is a lack of research investigating correlations between specific motor impairments and autistic traits.

Additionally, there is evidence that SES impacts the development of autism, although the insufficient literature on this relationship has previously been highlighted (Olson et al., 2021). Studies in the United States have found evidence for a relationship between autism diagnosis and SES, where children of higher SES are more likely to be diagnosed with autism, which may be due to increased knowledge about the disorder and increased access to healthcare services in higher socioeconomic levels (Dickerson et al., 2017; King & Bearman, 2011; Thomas et al., 2012). Similarly, the rates of referral for autism diagnosis in Israel differ between the Bedouin-Arabic and Jewish ethnic groups, which are also known to differ socioeconomically (Levaot et al., 2019). In contrast, a study in Denmark found no association between SES of the family and probability of receiving an autism diagnosis (Larsson et al., 2005), which may be due to the fact that healthcare services are available to all people in Denmark irrespective of SES. However, a study in Sweden found that lower SES associated with an increased chance of being diagnosed with autism, and healthcare services are similarly widely available in Sweden as in Denmark (Rai et al., 2012). The relationship between diagnosis and lower SES in Sweden indicates the potential for environmental factors associated with SES to play a role in the development of autism. However, there is currently very little data on the relationship between SES and autism traits. A study in Malaysia has found employment status of the father to predict autistic traits in the child (Eow et al., 2020). In the United States, maternal education level has been shown to affect both expressive and receptive language development in autistic children (Olson et al., 2021). There is the potential for higher SES to act as a moderating influence on autism characteristics, with higher SES providing access to earlier diagnosis and a wider variety of therapy and support options. This theory is supported by a study in which SES was demonstrated to relate to developmental trajectory in autistic children, with higher SES associating with increased developmental gains over time (Fountain et al., 2012). Additionally, a study in Egypt showed higher SES to relate to increased adaptive functioning when autism trait severity was controlled for (Ibrahim, El-abdeen, Ng, Zoromba, & Haikal, 2020).

In this study we set out to assess relationships between SES, motor skills and degree of social and behavioral autistic traits in a cohort of children in the City of Johannesburg (South Africa). The objectives of the study were to investigate the presence of linear correlations between motor skills and autism traits, and SES and autism traits.

1. Methods

1.1. Ethical approval

The experimental protocol for this study was approved by the Human Research Ethics Committee of the University of the Witwatersrand, Johannesburg, South Africa (clearance number M180767), and was conducted in accordance with standards laid out by the Declaration of Helsinki. Informed consent was obtained from the parents or legal guardians of all participants from whom data was collected. Once informed consent was obtained from a parent or guardian, assent was obtained from each child participating in the study. If a child expressed (at any point during the study) that they did not wish to complete a certain data collection activity, this was respected. This means that not all forms of data were collected for every participant.

1.2. Participants

Children between the ages of 8 and 18 years, who had been previously diagnosed with autism were recruited through the Centre for Autism Research and Education (CARE) and through the Fight with Insight clinic, which conducts structured exercise classes for autistic children out of the Children's Memorial Institute (CMI). A clinical diagnosis of autism is required for the enrolment of children at both schools. Recruitment was conducted by sending information sheets and consent forms home with all eligible children for parents/guardians to read and sign if they decided that they wanted their child to participate. Participants were not excluded for any health reason, but all participants were of medium- to low-support needs, as these children were more able to participate in the data collection activities. Support need level is a relative measure and is assessed subjectively by the teachers in each school, who group children into classes together on the basis of having similar levels of support requirements. Children with greater communicative difficulty were not included in the study, as this affected their ability to understand and complete the tasks involved in the motor assessment. The sample size for the correlation analysis was determined using a power analysis with a desired effect size of 0.35, a significance level of 5%, and a desired power of 80%, resulting in a required sample size of 46 children. Approximately 80 children in total were approached for recruitment, and non-response was taken as lack of consent to participate.

1.3. *Experimental protocol*

Subjective social and behavioral autism traits were assessed using the Autism Treatment Evaluation Checklist (ATEC) by a parent or caretaker who knew the child well. A short questionnaire assessing socioeconomic status was also completed by a parent or caregiver. Motor skills were assessed using the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) conducted with each participant by the first author. All measures for each participant were collected within a month of each other. The details of each assessment are provided below.

1.3.1. *Socioeconomic status questionnaire*

A socioeconomic status questionnaire was completed by a parent or guardian of each participant. The questionnaire used to assess socioeconomic status was based on Bagwath Persad et al. (2017), which was developed as a suitable measure of socioeconomic status in the South African context. The questionnaire assesses parent/caregiver level of education using ordinal categories. Employment status and assets owned in the home are assessed with yes/no items. A composite score was created for the questionnaire by numerically rating the possible answers on the items. A higher score indicates a higher socioeconomic status, with the maximum possible score on the questionnaire being 9 points.

1.3.2. *The Autism Treatment Evaluation Checklist*

A caregiver (parent, guardian or teacher) of each participant completed an ATEC form assessing the participant. The ATEC scores degree of autistic traits in four different domains, namely: (1) Speech/Language/Communication, (2) Sociability, (3) Sensory/ Cognitive Awareness and (4) Health/Physical/Behavior. Each domain consists of between 14 and 25 items that are each scored on a Likert-type scale. Scores for each domain in addition to an overall score were obtained for each participant by numerically rating the possible answers. A lower score in each domain indicated a higher degree of the trait assessed, with the maximum scores for each domain being 28, 40, 36 and 75 respectively. The maximum possible score for the overall ATEC is therefore 179. The ATEC is freely available to download from https://www.aitinstitute.org/AIT_FORMS/ATEC.pdf and does not require training in order to be administered.

1.3.3. *The Bruininks-Oseretsky Test of Motor Proficiency*

The lead researcher assessed each participant individually using the full-form BOT-2 motor assessment kit. The BOT-2 assesses motor proficiency in four different domains and has been used previously to quantify motor improvements in children with autism (Najafabadi et al., 2018; Srinivasan et al., 2015). The BOT-2 was developed in America based on standards from typically-developing children (Bruininks, 2005). The BOT-2 has been found to be a reliable and internally consistent motor skills measurement tool (Wuang & Su, 2009). The four domains assessed by the BOT-2 are (1) Fine Manual Control, (2) Manual Co-ordination, (3) Body Co-ordination and (4) Strength & Agility. Each domain is scored on two sub-domains and each sub-domain consists of between 5 and 8 motor activities completed by the participant. The sub-domains are (1a) Fine Motor Precision, (1b) Fine Motor Integration, (2a) Manual Dexterity, (2b) Upper-limb Co-ordination, (3a) Bilateral Co-ordination, (3b) Balance, (4a) Running Speed & Agility and (4b) Strength. Performance in each domain and sub-domain was scored by the lead researcher according to rules laid out by the BOT-2 manual, where a higher score indicates a higher proficiency in that domain. A composite score for overall motor proficiency was obtained from all four domains. The raw scores for performance in each domain and subdomain were converted to a sex-specific, age-appropriate scale score using tables provided in the BOT-2 manual. These scale scores were then converted to standard scores for comparison with one another and for presentation as group data.

1.4. *Data analysis and statistical testing*

Each data set was tested for normality using the Shapiro-Wilk test. The relationships between socioeconomic status score, and each ATEC and BOT-2 score (domain scores as well as composite scores) for each participant were assessed using different correlation approaches as described below. Relationships between scores obtained on the ATEC and scores obtained on the BOT-2 were also assessed. Spearman's correlation was used for the non-parametric variables, while Pearson's correlation was used for the parametric variables. Only complete cases were included in each correlation analysis (sample sizes for each analysis are given in the Results section). All statistical tests were performed using the core package and the plyr and tidyr packages in R statistical software (R Core Team, 2016; Wickham, 2011, 2017) and significance was set at $p = 0.05$.

2. Results

2.1. Sample characteristics

Data were collected from 50 participants in total, and the median age of the sample was 13 years (IQR = 11 – 15). The sample was 92% male (n = 46) and 8% female (n = 4). The race of the sample was 84% Black (n = 42), 8% White (n = 4) and 8% Indian (n = 4). A summary of the descriptive characteristics of the sample is given in Table 1. Approximately 54% (22 out of 41) of the ATEC forms were completed by a parent of the participant, while the rest were completed by the participant's teacher. Where communication and follow-up with the parents was difficult, teacher reports were used instead. The ATEC was designed to be completed by any caregiver, including teachers. Not all measures were collected for all 50 participants, and reasons for incomplete participation were not always provided by participants. In some cases, completed ATEC forms were never returned by parents and follow-up was difficult in cases where contact details had not been provided. Additionally, the lockdown state as a result of COVID-19 restrictions curtailed the conduct of motor assessments and further complicated follow-up with parents for completed forms.

2.2. Correlations between socioeconomic status, ATEC scores and BOT-2 scores

Table 2 shows correlation co-efficients and p-values for relationships found between ATEC scores and BOT-2 scores, analyzed from the sub-set of the sample that completed both the ATEC and the BOT-2 (n = 19). No significant relationships were found between socioeconomic status and any of the ATEC scores (Table 3, n = 35) or between socioeconomic status and any of the BOT-2 scores (Table 4, n = 25).

3. Discussion

In this study we looked for relationships between SES, motor skills and autistic traits in our cohort. Strong relationships between all motor skill domains and subdomains and the Speech/Language/Communication and Sensory/Cognitive Awareness domains of the ATEC were found. Sociability correlated with every motor skill domain and subdomain with the exception of Manual Dexterity. The Health/Physical/Behaviour section of the ATEC showed weak correlations with two subdomains, namely Fine Motor Precision and Balance, as well as the Body Co-ordination domain of the BOT-2. The presence of stronger and more consistent relationships between motor skills and the first three sections of the ATEC indicate that motor skills may have either a role in, or a shared underlying mechanism with Speech/Language/Communication, Sociability and Sensory/Cognitive Awareness which is more separate to the mechanisms underlying the Health/Physical/Behaviour aspects of autism. However, although we hypothesized a link between autism and SES, we found no correlation between SES and either autistic traits or motor skills.

Our results showing a lack of relationships between autistic traits and SES may indicate that SES is not a primary environmental factor involved in the development of autism. However, SES may still be a moderating factor in the prognosis of autism, since families of higher SES are more likely to have access to support services and informative resources. A study in Australia found SES to act as a

Table 1
Summary statistics for socioeconomic status, ATEC and BOT-2 scores in a sample of South African autistic children (total n = 50).

Variable	Summary statistics	Norm Scores
Socioeconomic status (n = 48)	9 (7.00 – 9)	
ATEC scores (n = 41)		
Speech/Language/Communication	22 (14 – 25)	
Sociability	29 (22 – 35)	
Sensory/Cognitive Awareness	28 (24 – 32)	
Health/Physical/Behaviour	65 (50 – 71)	
ATEC composite	138 (108 – 161)	
BOT-2 scores (n = 25)		
Fine Motor Precision	7.9 ± 3.3	15 ± 5
Fine Motor Integration	9.0 ± 4.4	15 ± 5
Manual Dexterity	5.1 ± 2.3	15 ± 5
Bilateral Co-ordination	8.0 (7.0 – 12.0)	15 ± 5
Balance	10.0 (6.0 – 15.0)	15 ± 5
Running Speed & Agility	7.0 (6.0 – 8.0)	15 ± 5
Upper-limb Co-ordination	11.9 ± 7.1	15 ± 5
Strength	6.8 ± 2.6	15 ± 5
Fine Manual Control	35.2 ± 6.9	50 ± 10
Manual Co-ordination	34.6 ± 8.7	50 ± 10
Body Co-ordination	37.4 ± 10.7	50 ± 10
Strength & Agility	33.4 ± 5.8	50 ± 10
BOT-2 Composite	32.6 ± 6.6	50 ± 10

Note: ATEC = Autism Treatment Evaluation Checklist, BOT-2 = Bruininks-Oseretsky Motor Proficiency Test Second Edition. Parametric data is presented as mean ± SD, while non-parametric data is represented as median (IQR).

Table 2
Results of correlational assessments conducted between ATEC scores (across) and BOT-2 scores (down) for a South African autistic sample (n = 19).

BOT-2 variable	Speech/ Language/ Communication	Sociability	Sensory/ Cognitive Awareness	Health/ Physical/ Behaviour	ATEC Composite
Fine Motor Precision	**0.615 (0.005)***	**0.633 (0.004)***	**0.714 (<0.001)***	**0.493 (0.032)***	**0.637 (0.003)***
Fine Motor Integration	**0.567 (0.011)***	**0.490 (0.033)***	**0.591 (0.008)***	0.405 (0.085)	**0.523 (0.022)***
Fine Manual Control	**0.631 (0.004)***	**0.558 (0.013)***	**0.671 (0.002)***	0.401 (0.089)	**0.575 (0.010)***
Manual Dexterity	**0.616 (0.005)***	0.362 (0.128)	**0.503 (0.028)***	0.102 (0.678)	**0.469 (0.043)***
Upper-limb Co-ordination	**0.694 (0.001)***	**0.505 (0.0528)***	**0.622 (0.004)***	0.320 (0.181)	**0.598 (0.007)***
Manual Co-ordination	**0.703 (0.001)***	**0.522 (0.022)***	**0.640 (0.003)***	0.290 (0.229)	**0.629 (0.004)***
Bilateral Co-ordination	**0.616 (0.005)***	**0.524 (0.021)***	**0.510 (0.026)***	0.437 (0.062)	**0.625 (0.004)***
Balance	**0.701 (0.001)***	**0.770 (<0.001)***	**0.762 (<0.001)***	**0.485 (0.035)***	**0.819 (<0.001)***
Body Co-ordination	**0.669 (0.002)***	**0.760 (<0.001)***	**0.742 (<0.001)***	**0.553 (0.014)***	**0.830 (<0.001)***
Running Speed & Agility	**0.605 (0.006)***	**0.551 (0.015)***	**0.602 (0.006)***	0.423 (0.071)	**0.607 (0.006)***
Strength	**0.767 (<0.001)***	**0.573 (0.010)***	**0.729 (<0.001)***	0.281 (0.245)	**0.573 (0.010)***
Strength & Agility	**0.702 (0.001)***	**0.658 (0.002)***	**0.775 (<0.001)***	0.415 (0.077)	**0.693 (0.001)***
BOT-2 Composite	**0.780 (<0.001)***	**0.670 (0.002)***	**0.775 (<0.001)***	**0.458 (0.049)***	**0.760 (<0.001)***

Note: ATEC = Autism Treatment Evaluation Checklist, BOT-2 = Bruininks-Oseretsky Motor Proficiency Test Second Edition. Correlation co-efficients (p-values) are presented, with significant relationships given in bold and marked with an asterisk (*). Pearson's correlation test was used for the normally-distributed variables, while Spearman's correlation test was used for non-normally-distributed variables. Significance was set at $p < 0.05$.

Table 3
Results of correlational assessments conducted between ATEC scores and socioeconomic status for a South African autistic sample (n = 35).

ATEC variable	Correlation co-efficient	p-value
Speech/Language/Communication	-0.061	0.726
Sociability	-0.001	0.997
Sensory/Cognitive Awareness	-0.165	0.343
Health/Physical/Behaviour	-0.002	0.991
ATEC Composite	-0.037	0.832

Note: ATEC = Autism Treatment Evaluation Checklist. Pearson's correlation test was used for the normally-distributed variables, while Spearman's correlation test was used for non-normally-distributed variables. Significant relationships given in bold and marked with an asterisk (*), significance was set at $p < 0.05$.

moderating factor on the negative relationship between parental competency and autistic traits (Mathew et al., 2019), which supports this hypothesis. The fact that we found no evidence of a relationship could be due to the complex nature of the relationship. Additionally, we did not recruit a great range of SES in our cohort, and the lack of a significant relationship may also be due to the fact that our sample was not fully representative of the socioeconomic levels present in the wider population.

We found significant relationships between all motor domains and three of the ATEC domains, which is suggestive of a possible shared aetiology between environmental awareness, social and communicative skills and motor capability in this sample of ASD individuals. Future studies are needed to corroborate these results, and as we did not factor corrections for multiple correlations into our analyses, the exploratory nature of our findings must be kept in mind. While motor impairment is not currently considered a diagnostic feature of autism, the relationships observed here are consistent with previous findings on associations between various aspects of autistic traits and motor skills (Bhat et al., 2018; Freitag et al., 2007; C. L. Hilton et al., 2012; MacDonald et al., 2013, 2014; Travers et al., 2013). Moreover, development of social skills in young autistic boys has been found to correlate positively with gross motor skills and core stability, with specific impairments of stability, motor accuracy and object manipulation predicting impairments in social function (Holloway et al., 2018). Relationships between motor ability and IQ (Green et al., 2009; Kaur et al., 2018; Surgent et al., 2021) and between motor ability and sensory symptom severity (Surgent et al., 2021) have been found in children with and without autism. Magnitude of risk for motor impairment has also been found to relate to severity of impairment in social communication, functioning, cognition, language and repetitive behaviours (Bhat, 2021). It is noteworthy, however, that Kaur et al. (2018) used the BOT-2 in

Table 4
Results of correlational assessments conducted between BOT-2 scores and socioeconomic status for a South African autistic sample (n = 25).

BOT-2 variable	Correlation co-efficient	p-value
Fine Motor Precision	-0.206	0.323
Fine Motor Integration	-0.161	0.442
Fine Manual Control	-0.195	0.349
Manual Dexterity	-0.195	0.351
Upper-limb Co-ordination	0.016	0.938
Manual Co-ordination	0.028	0.893
Bilateral Co-ordination	-0.064	0.763
Balance	-0.165	0.431
Body Co-ordination	-0.104	0.621
Running Speed & Agility	-0.265	0.200
Strength	-0.123	0.558
Strength & Agility	-0.225	0.279
BOT-2 Composite	-0.162	0.440

Note: BOT-2 = Bruininks-Oseretsky Motor Proficiency Test Second Edition. Pearson's correlation test was used for the normally-distributed variables, while Spearman's correlation test was used for non-normally-distributed variables. Significant relationships given in bold and marked with an asterisk (*), significance was set at $p < 0.05$.

assessment of neurotypical children as compared with autistic children, and found that motor impairment did not correlate with scores on the Autism Diagnostic Observation Schedule. We chose the ATEC as our assessment of trait degree, and while the ATEC was not developed to describe autism characteristics in a population but rather to track changes in autism traits over time, it has been used previously to describe autistic characteristics in a sample (Al Shirian & Al Dera, 2015; Deng et al., 2007). As it was primarily developed to track changes in characteristics over time, it may not be a good tool to provide comparisons between individuals. However, we believe that it still has validity as a holistic measure of traits and behaviours present in a group. It is also a free to use assessment tool that requires no training to administer, making it well-suited to use for research and assessment in low-resource settings such as South Africa. To our knowledge, the ATEC has not previously been used to assess relationships between autistic traits and motor skills. Our findings add to the literature investigating the relationships between motor impairment in autism and autistic traits, and provide support to the idea that motor impairment could be a core component of autism.

Motor skills may either be a requirement for social and communicative behaviors or may share underlying neurological infrastructure with social/communicative behaviours. The relationships between motor impairment and language difficulties observed in several studies support theories of a neurological link between motor functionality and language development (Bedford et al., 2016; Bhat et al., 2018; Bhat, 2021; Gernsbacher et al., 2008; McPhillips et al., 2014; Noterdaeme et al., 2002). The requirement for motor capacity in the oral formation of words (and the manual formation of words in the case of deaf children and those who use assisted communication methods such as Makaton) presents an obvious link between the two functions, but many other underlying relationships could be occurring. The Health/Physical/Behaviour component of the ATEC assesses the aspects of autism that are less closely related to sociability and communication, such as sleep disturbances, gastrointestinal complaints, destructive actions and perseverative behaviours. The fact that we found very few correlations between our BOT-2 scores and the Health/Physical/Behaviour domain of the ATEC is therefore in keeping with the theory presented above and could be indicative that the behaviours assessed in this domain arise from a relatively separate neurological cause.

A study comparing autistic children to children with ADHD or a disorder of developmental co-ordination found similar motor impairment across groups, but gestural impairment only in the autistic group, which suggests that gestural impairment may not be solely due to the motor deficits present (Dewey et al., 2007). In their study of dyspraxia in autism, Mostofsky et al. (2006) also suggest that the body-part-for-tool errors observed in autism imply that dyspraxia is also not solely due to motor deficits. Neurologically, the authors suggest an impairment of the circuitry responsible for acquisition and representation of motor sequences, specifically the subcortical circuitry between the frontal and parietal regions. In alignment with this theory, differences in frontal and parietal morphology have also been observed in autistic brains as compared with neurotypical brains, specifically increases in grey matter and surface area in the pre-central and post-central gyri as well as the inferior parietal cortex (Mahajan et al., 2016). The observation by Carmo et al. (2013) that autistic children perform known gestures better than novel gestures supports a theory of impairment in the learning and acquisition of motor sequences.

Additionally, sensory awareness is likely to be necessary for accurate motor actions and responses. In a study on postural stability, Minshew et al. (2004) found that somatosensory disruption increased postural instability in autistic children. Vanvuchelen et al. (2007) have suggested that the impairment of imitation observed in autism implicates an impairment of perceptual-motor integration. Impaired perceptual-motor integration may be responsible for difficulties in adapting movements to changing task demands (Whyatt & Craig, 2013). This is supported by fMRI evidence that there is asynchrony between the visual and motor systems in autism, and that the severity of this asynchrony correlates with the degree of autistic traits (Nebel et al., 2016). Degree of social/communicative autistic traits has also been found to associate with decreased connectivity between the posterior cerebellum and the left inferior parietal lobule, which is an important circuit for visuomotor processing (Lidstone et al., 2021). Interestingly, positive relationships have been observed between social responsiveness and sensory processing in autism (Hilton et al., 2007), which suggests a role for sensory processing in social behaviour as well. Social motor synchronisation has been found to associate with degree of autistic traits in a way that is not fully accounted for by motor deficits (Fitzpatrick et al., 2017). We suggest that the triad discussed here (social/-communication, motor and sensory processing) are neurologically inter-related and functionally interdependent.

Some studies have shown that similar motor impairment exists in other developmental disorders as that observed in autism. About 87% of autistic children have been estimated to be at risk of motor impairment (Bhat, 2020), which highlights the importance of recognising and understanding the patterns of motor impairment specific to autism. One study found that autistic children have similar fine and gross motor profiles to children with developmental delay (Provost et al., 2007). Similarly, Noterdaeme et al. (2002) found that both autistic children and children with either an expressive or receptive language disorder have more motor impairments than typically-developing controls. Children with Asperger's Syndrome have been noted to overlap with children with a specific disorder of motor function in their motor impairment profiles (Green et al., 2002). In a study comparing children with Asperger's Syndrome to children with learning disabilities, motor delay was found in both groups, with similar impairment profiles once again. However, a significant difference in manual dexterity was observed between the two groups, with the Asperger's group showing poorer performance in that domain (Miyahara et al., 1997). Autistic children and children with a specific language impairment have been found to show similarly impaired motor profiles, with the exception once again where autistic children showed poorer performance on a manual dexterity task that involved both hands (McPhillips et al., 2014). A recent review of MRI literature concluded that the neural correlates observed for autism and developmental co-ordination disorder show different patterns, suggesting that these conditions are neurologically distinct (Kangarani-Farahani et al., 2022). A limitation of our own study is that we did not collect information on co-occurring disorders in our cohort and therefore cannot take this information into account in interpreting our findings. For future studies it may be important to look at comparing autistic motor deficits with those present in other populations with developmental disorders, to identify syndrome-specific difficulties and therefore more targeted therapies.

Our study has identified relationships between motor skills and degree of autistic traits in the domains of social behaviour, language/communication and sensory/cognitive awareness. These results support previous research highlighting the centrality of motor impairment in autistic traits. These findings have relevance for the further development of diagnostic criteria for autism, as well as for the implementation of appropriate support strategies. We suggest an interlinking and interdependence of neurological structures underlying social/communicative function, sensory processing and motor development. Interventions strategies for autism therefore need to be aimed at integrating these three domains. We did not find any evidence for a relationship between SES and autism trait degree. However, future studies assessing the relationship between SES and autistic characteristics need to make extra effort to include participants of lower SES in their cohorts.

CRediT authorship contribution statement

de Lange Siobhan: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Dafkin Chloe:** Supervision, Validation, Writing – review & editing. **Muller Dee:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

Data Availability

Data will be made available on request.

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