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ORIGINAL PAPER

Literacy and Numeracy in Children on Autism Spectrum Disorder

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Abstract

Objectives The variability in patterns of acquisition of literacy and numeracy skills in young children with autism spectrum disorder (ASD) is currently not well understood. In the present study, we investigated these skills in cognitively able children with ASD ages 7–12 years.

Methods Using independent samples *t* test, we compared autistic children's scores on word reading, spelling, and numerical operations with those of typically developing children in the same age group. A paired-samples *t* test was used to assess whether reading, spelling, and numerical operations scores were comparable within the ASD group. Finally, we tested whether verbal IQ mediated the effect of diagnostic status on these scores.

Results The main findings of the study are that autistic children had worse scores on numerical operations than the control group ($t(54.112) = -3.326$, $p = .002$, $d = -.314$), but the groups' scores were similar in word reading and spelling. The autistic children had significantly better scores on word reading and spelling than on numerical operations. All scores of autistic children were positively associated with their verbal IQ scores. Verbal IQ mediated the effect of diagnostic status on all outcome variables.

Conclusion These findings extend current understanding of patterns of acquisition of literacy and numeracy skills in young children with ASD, suggesting a critical role of verbal abilities in the acquisition of numerical skills.

Keywords Autism spectrum disorders · Word reading · Spelling · Numerical operations · Verbal IQ

Autism spectrum disorder (ASD) is a heterogeneous set of neurodevelopmental disorders, characterized by deficits in social cognition, mentalizing, reasoning, and other aspects of higher cognition, such as use of complex language, including figurative language and comprehension of humor, as well as verbal learning, attention and vigilance, working memory, and speed of processing (American Psychiatric Association, 2000, 2013; Frith, 2001; Kljajevic, 2019; Lever & Geurts, 2016; Velikonja et al., 2019). The disorder is defined as a spectrum, because of variance in the constellation and severity of symptoms in individuals with ASD (Rosen et al., 2021). An intellectual disability characterizes an estimated 30% of individuals with autism, which contributes to large individual differences in their performance on cognitive tests and heterogeneity of the disorder (Åsberg Johnels et al., 2021; Westerveld & Paynter, 2021). Furthermore, individuals with ASD may show hyper- or hypo-sensitivity to sensory inputs, have restricted interests, and restricted or repetitive behavioral patterns that negatively affect quality of life (Finnegan & Accado, 2018; John et al., 2018). In addition to variability in symptoms, cognitive abilities, and patterns of behavior, the disorder is associated with deviation from typical brain development, such as enlargement of grey and white matter in frontal, temporal, and parietal areas (Di Martino et al., 2014), deviation from cortical shape, increased cortical thickness (Amaral et al., 2008), and altered anatomical and functional connectivity (Keown et al., 2013; Rudie & Dapretto, 2013; Zeng et al., 2017), which may preclude optimal modulation of brain activity levels required by cognitive tasks (Supekar et al., 2013).

Until recently, autism was largely considered a relatively rare disorder, but growing evidence suggests its much higher prevalence (Elsabbagh et al., 2012). For instance, prevalence of autism in 8-year-olds in a sample of 325,483 children recruited from across the USA in 2014 was 16.8 in 1000, which means that one child in 59 children that age was

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autistic (Baio et al., 2018). Research on academic achievement in autistic children suggests that their ability profiles may be affected by age and IQ, with brighter children being diagnosed later (Mayes & Calhoun, 2003). An estimated 30% of autistic children have functional verbal language difficulties, which may be present even when their intellectual functioning is in the range of average neurotypically developing children, and they often have difficulties in aspects of literacy (Murdaugh et al., 2017).

An area of high individual variability in children with autism that remains relatively understudied, in particular in younger children, is literacy and numeracy (Åsberg Johnels et al., 2021; Westerveld & Paynter, 2021). According to one prominent model of neuropsychologic functioning in autism, high functioning autistic individuals perform well on tasks that require "mechanical academic skills," such as spelling, reading accuracy, numerical operations, visual-auditory learning, and similar, whereas they have marked difficulties in tasks that require interpretative skills, logical reasoning, and comprehension of complex materials (Goldstein et al., 1994; Minshew et al., 1997). The model, therefore, predicts that cognitively able autistic individuals have word reading, spelling, and numerical operations at the level comparable to neurotypical population.

However, evidence so far indicates that there exist different patterns of acquisition of literacy and numeracy in young children with ASD (Chen et al., 2019; Goldstein et al., 1994; Iuculano et al., 2020; Jones et al., 2009; May et al., 2015), and this variability is not well understood. For example, Goldstein et al. (1994) found that young autistic children (< 13 years of age) performed significantly better than their typically developing peers on reading decoding, spelling, and math calculations. The two groups had similar verbal IQ scores. May et al. (2015) studied development of word reading and math skills in a group of 7–12 years old children with ASD over one year. Although the ASD group had lower verbal IQ scores compared to typically developing children, there were no statistically significant group differences in word reading and numerical operations scores at baseline or developmental differences in these skills in children with ASD. Similarly, Iuculano et al. (2020) found that high-functioning autistic children between 7 and 12 years of age achieved scores on word reading and numerical operations that were not statistically significantly different from the scores of the typically developing group matched for age, sex, and IQ, but there was a difference in how their brains executed the tasks. Thus, these studies suggest that, regardless of verbal IQ, autistic children have literacy and numeracy skills comparable to or even better than typically developing children.

Alongside these findings, there is also evidence that young autistic children have more difficulty with numerical operations than with word reading and spelling. For example, Aagten-Murphy et al. (2015) reported that autistic children between 8 and 13 years of age performed significantly worse than their typically developing peers on numerical operations, even though the groups did not differ in IQ scores and all children were considered cognitively able, achieving full scale IQ scores > 70. Another study, in which autistic children between 7 and 12 years of age were matched in age, sex, and IQ with typically developing children, found that children with ASD performed similarly to typically developing children on word reading, but significantly worse on numerical operations (table S1 in Chen et al., 2019). Thus, these two studies suggest a pattern that is not predicted by the model of neuropsychologic functioning in autism described above (Goldstein et al., 1994).

Taken together, these studies indicate a great degree of variability in acquisition of literacy and numeracy skills in young children with ASD. Considering that difficulties in communication define ASD, one could hypothesize that language, and by extension literacy skills, would be worse in children with this disorder than in their neurotypical peers. At the same time, one widespread myth on autism is that individuals with this disorder have above average mathematical skills (Aagten-Murphy et al., 2015; John et al., 2018), and there is evidence suggesting that individuals with superior mathematical skills are more often diagnosed with autism than others (Bressan, 2018). Given the pivotal role of literacy and numeracy in early education and later on in work and everyday life, the goal of the present study was to examine basic literacy and numeracy skills in cognitively able young autistic children with lower verbal IQ relative to typically developing children in the same age group and whether verbal IQ intervenes in acquisition of these skills.

Methods

Participants

The study sample consisted of 67 children, 48 of whom were diagnosed with ASD, while the remaining 19 were typically developing children (TYP). All children were between 7 and 12 years of age (ASD: M = 8.27 years, SD = 1.44; TYP: M = 8.95, SD = 1.47). There were considerably more boys than girls (ASD: 43 boys, 5 girls; TYP: 19 boys, 0 girls). There were 27 right-handed, 5 left-handed, and 10 ambidextrous children in the ASD group (six children had no handedness data reported) and 18 right-handed children, no left-handed, and one ambidextrous child in the TYP group. Among the children with ASD, 30 children (62.5%) had some form of non-ASD psychiatric disorder, such as depression, obsessive compulsive disorder, generalized anxiety disorder, phobia, transient/chronic vocal tic disorder, ADHD, or some combination of these conditions. At the time of testing, six children with ASD were taking medications: one child was taking melatonin, another child atomoxetine, two children were on methylphenidate, while the remaining two children were taking methylphenidate in combination with one or two other medications as appropriate given the additional conditions (e.g., quanfacine, fluoxetine).

Procedure

Data for the present study were obtained from the Autism Brain Imaging Data Exchange (ABIDE) database (http://fcon_1000.projects.nitrc.org). Briefly, ABIDE is a multicenter study with a publicly available repository of neuroimaging (structural MRI and resting state fMRI), behavioral, clinical, and cognitive data on individuals with ASD and typically developing individuals. Originally, the consortium consisted of 17 sites that contributed altogether 1112 datasets from 539 individuals with ASD and 573 control subjects (age range: 7–64 years). These data have been available to the scientific community since August 2012. The first ABIDE initiative was followed by ABIDE II, which included 19 sites from the USA and Europe (all high-income countries) that contributed 1114 datasets from 521 individuals with ASD and 593 control subjects (age range: 5–64 years). These data have become freely available in June 2016. In accordance with HIPAA guidelines and 1000 Functional Connectomes Project/INDI protocols, all datasets are anonymous (http://fcon_1000.projects.nitrc.org/indi/abide/abide_II.html). Each site that contributed data obtained ethics approval from their Institutional Review Board and conducted research in accordance with the Helsinki Declaration guidelines on research with human subjects (Di Martino et al., 2014; Riddle et al., 2017). To obtain access to ABIDE data, the requirement is that users register with the NITRC and 1000 Functional Connectomes Project. Data usage is unrestricted for non-commercial research purposes. Data for the present study were downloaded in spring of 2021, following the protocol and focusing on children with available literacy and numeracy scores.

Measures

The word reading, spelling, and numerical operations data used in the present study were obtained from the ABIDE II records. The ABIDE II study assessed word reading, spelling, and numerical operations using Wechsler Individual Achievement Test, Second Edition, Abbreviated (henceforth WIAT-II) (Wechsler, 2005). Additional data included in the present study are participants' verbal IQ standard scores, Social Communication Questionnaire (SCQ) scores (Rutter et al., 2003), along with ASD children's scores on assessments of autism: Autism Diagnostic Interview-Revised (ADI-R) (Le Couteur et al., 2003) and Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 2000). Participants' characteristics and relevant scores, including ASD children's scores on autism diagnostic assessments, are reported in Table 1.

Data Analyses

Independent samples *t* test was used to compare the groups on age and scores on word reading, spelling, and numeracy, as well as on verbal IQ and SCQ. The results were adjusted for multiple comparisons using a Bonferroni correction (0.05/6 = 0.008). Since the handedness scores were not normally distributed, as indicated by the values of skew (−2.037, $SE_{skewness} = 0.306$) and kurtosis (3.896, $SE_{kurtosis} = 0.604$), Mann–Whitney test was used to compare the groups' scores. A paired samples *t* test was used to compare ASD children's scores on word reading, spelling, and numerical operations in order to determine whether their literacy and numeracy abilities were comparable. Cohen's *d* indicating size of the effects was calculated from the sample standard deviation of the mean difference. Pearson correlation coefficient (*r*) was calculated to determine possible associations between the ASD children's scores on word reading, spelling, and numerical operations, on the one hand, and their verbal IQ scores, on the other, and Spearman correlation coefficient (r_s) for possible associations

Table 1 Participants' demographic characteristics, cognitive scores, and ASD children's scores on autism diagnostic measures

Measure	ASD (*n* = 48)	TYP (*n* = 19)
Age	8.27 (1.45)	8.95 (1.47)
Sex (male/female)	43/5	19/0
Handedness (RH/LF/Amb)	27/5/10[a]	18/0/1
Handedness scores (mean, SD)	47.1 (50.6)	71.5 (18.2)
VIQ	102.77 (17.27)	121.47(13.37)
SCQ total	16.49 (7.67)	2.74 (1.76)
WIAT-II word reading Range	108.87 (17.13) 58–141	116.37 (13.34) 84–143
WIAT-II spelling Range	107.03 (20.1) 62–142	113.16 (13.5) 85–133
WIAT-II numeracy Range	101.18 (21.36) 52–156	115.63 (12.9) 93–141
ADI-R-Social	17.68 (6.45)	-
ADI-R-Verbal	15.33 (5.03)	-
ADI-R-Nonverbal	8.73 (3.63)	-
ADI-R-RRB	5.63 (2.62)	-
ADI-R-Onset	3.19 (1.35)	-
ADOS-G-Communication	2.71 (1.73)	-
ADOS-G-Social	7 (2.23)	-

Means with standard deviations presented in parentheses. *ASD*, autistic spectrum disorder; *TYP*, typically developing children; *RH*, right-handed; *LH*, left-handed; *Amb*, ambidextrous; *VIQ*, verbal IQ standard scores; *SCQ*, Social Communication Questionnaire; *ADI-R-Social*, Autism Diagnostic Interview-Revised reciprocal social interaction subscore; *ADI-R-Verbal*, abnormalities in communication subscore verbal; *ADI-R-RRB*, restricted, repetitive, or stereotyped patterns of behavior; *ADI-R-Onset*, abnormality of development evident at or before 36 months; *ADOS-G*, Autism Diagnostic Observation Schedule-Generic

[a]Six ASD children (12.5%) lack handedness data

between these scores and their handedness scores. All tests were 2-tailed and performed in IBM SPSS Statistics for Windows, version 23 (Armonk, NY: IBM Corp).

In the next set of analyses, we tested whether participants' scores on verbal IQ mediated the associations between their diagnostic status and their scores on word reading, spelling, and numerical operations, while adjusting for age. The effect of interest in these analyses was the indirect effect, i.e., the product of *a* and *b*, where *a* is the path between the focal predictor, i.e., diagnostic status, and the mediator, i.e., verbal IQ, and *b* is the path between the mediator and outcome variable (word reading/spelling/numerical operations). We also report direct effects in these models, marked *c'*, i.e., the path leading directly from the focal predictor to the outcome variable, which indicates the effect of focal predictor on the outcome variable when controlling for age and verbal IQ. Since reporting standardized effects involving dichotomous focal predictors is strongly discouraged (Hayes, 2018), the reported effects are expressed in unstandardized metric. These analyses were performed using PROCESS, version 4.0 (www.afhayes.com) (Hayes, 2013, 2018), implemented in SPSS. Parameters were set to determine bias-corrected bootstrap confidence intervals based on 5000 bootstrap samples and the confidence interval was set at 95% value. A heteroscedasticity consistent standard error and covariance matrix estimator was used (Hayes & Cai, 2007).

Results

Although children with ASD were slightly younger than the children in the control group, the difference in age was not statistically significant ($t(32.648) = -1.731$, $p = 0.093$). The groups had similar handedness scores ($U = 306.500$, $z = -1.441$, $p = 0.150$, n.s.). Children with ASD had significantly lower verbal IQ scores than typically developing children ($t(42.537) = -4.732$, $p < 0.001$, $d = -1.148$). Consistent with the difference in their diagnostic profiles, there was a statistically significant group difference in children's SCQ scores, ($t(56.300) = 11.556$, $p < 0.001$, $d = 2.09$). The results of these analyses suggest large effects, according to Cohen's (1988) criteria.

Children with ASD performed considerably worse than TYP children on the test of numerical operations ($t(54.112) = -3.326$, $p = 0.002$, $d = -0.749$) (Fig. 1). The effect of this difference was large. However, there were no statistically significant differences between the groups' scores on word reading ($t(43.118) = -1.879$, $p = 0.067$) or spelling (t $(49.672) = -1.341$, $p = 0.093$).

Autistic children's scores on numerical operations were significantly worse than their scores both on word reading ($t(44) = -3.276$, $p = 0.002$, $d = -0.488$) and spelling ($t(44) = -2.817$, $p = 0.007$, $d = -0.420$), whereas the difference between their reading and spelling scores was not statistically significant ($t(44) = 0.914$, $p = 0.366$).

ASD group's verbal IQ scores were positively correlated with their scores on word reading ($r = 0.742$, $p < 0.001$), spelling ($r = 0.839$, $p < 0.001$), and numerical operations ($r = 0.686$, $p < 0.001$), but their handedness scores were not significantly associated with their scores on word reading ($r_s = -0.086$, $p = 0.518$), spelling ($r_s = 0.096$, $p = 0.468$), or numerical operations ($r_s = 0.046$, $p = 0.728$).

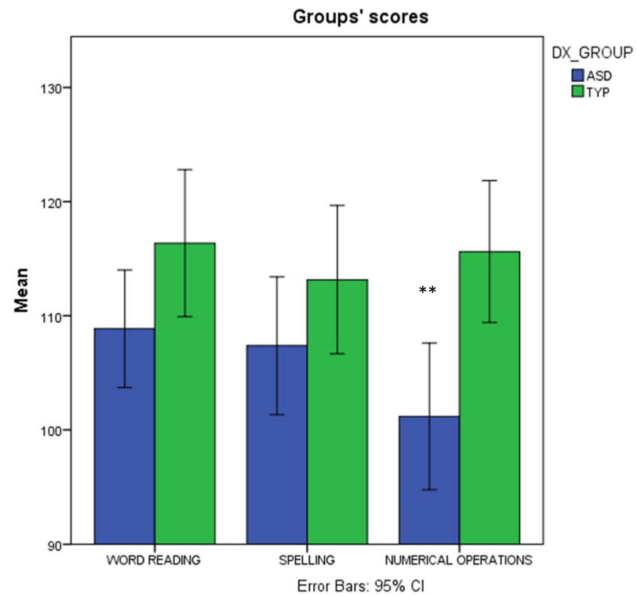

Fig. 1 Groups' scores on word reading, spelling, and numerical operations. *Note*. ASD, autism spectrum disorder; TYP, typically developing children. $^{**}p < .01$

There was a significant indirect effect of diagnostic status through verbal IQ on participants' scores in word reading (ab = 12.9301, 95% CI [6.8795, 19.7755]), spelling (ab = 11.7755, 95% CI [5.2574, 19.1315]), and numerical operations (ab = 14.3597, 95% CI [7.1799, 23.3786]) when controlling for age, but there was no evidence that the diagnostic status exerted a significant effect on participants' scores when verbal IQ and age were kept constant (Fig. 2).

Discussion

The present study investigated basic literacy and numeracy skills in children with ASD ages 7–12 years. The main findings of the study are better word reading and spelling relative to numerical operations in ASD children, and worse numerical operations but comparable word reading and spelling skills in autistic children relative to typically developing children. Even though the mean verbal IQ score of the ASD children in the present study was in the normal range, it was significantly lower than the IQ of the TYP children, who scored very high in IQ, and thus may not represent the population. Two recent studies that compared ASD and TYP children between 7 and 12 years of age, in which both groups had either very high verbal IQ scores (Iuculano et al., 2020) or normal-range IQ scores but with much lower scores in

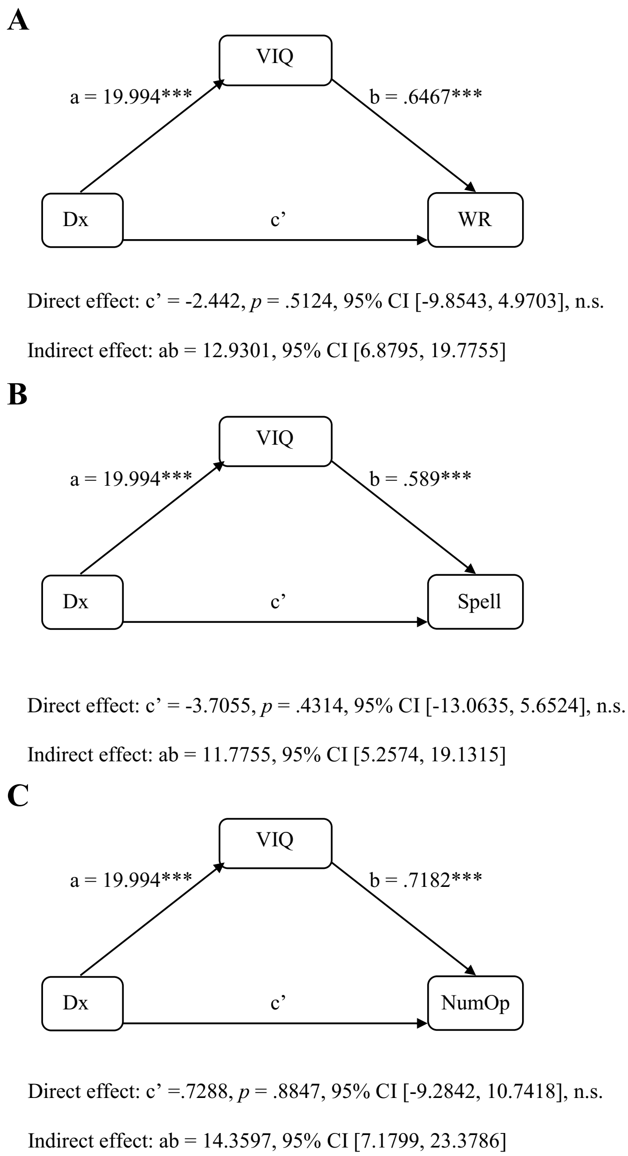

Fig. 2 Results of mediation analysis. *Note*. Results of mediation analysis showing a statistically significant indirect effect of diagnostic status (Dx) through verbal IQ on word reading (**A**), spelling (**B**), and numerical operations (**C**) and no significant direct effect. VIQ, verbal IQ; WR, word reading; Spell, spelling; NumOp, numerical operations. $***p < .001$

the ASD group (May et al., 2015), reported no significant differences in word reading and numerical operations scores between the groups. Thus, the present findings reflect an additional pattern of acquisition of literacy and numeracy skills in cognitively able 7–12-year-old autistic children.

Two other studies reported significantly worse performance of autistic children on numerical operations (Aagten-Murphy et al., 2015; Chen et al., 2019), but not on word reading (Chen et al., 2019) relative to their typically developing peers, but in these studies, ASD and TYP children had similar IQ scores. Although the numerical operations score of the autistic group in the present study falls within typical scores for their age, it is still significantly lower than their scores in word reading and spelling. This finding raises the question of whether further development of math skills is affected by this pattern of acquisition of numeracy skills in the subset of autistic children who have lower scores on numerical operations than on word reading and spelling and relative to the scores on numerical operations in the control group. The findings from the present study extend current understanding of the variability in basic literacy and numeracy skills in ASD by highlighting the intervening effect of verbal IQ in their acquisition. Experimental studies are necessary to disentangle which specific verbal abilities fall short of supporting acquisition of basic numeracy in autistic children.

Regarding the specific pattern found in the present study, one possible explanation relates to aberrant structural connectivity in the developing autistic brain. Recent findings on anatomical connectivity underpinning reading and numerical skills in neurotypical population suggest a critical role of two large fascicles in these skills: the superior longitudinal fasciculus (SLF) and the arcuate fasciculus (AF) (Grotheer et al., 2019). These two large white matter fascicles are implicated in language (Kljajevic, 2014; Rauschecker et al., 2009) and math (Tsang et al., 2009; Van Beek et al., 2014). Importantly, the reading and math tracts within these fascicles segregate into parallel sub-bundles that differ in myelination, with superior portion of SLF and AF correlating with math ability, and inferior portion correlating with reading ability, which suggests that atypical myelination of these tracts might be associated with reading and math disabilities (Grotheer et al., 2019). Since reading is often practiced more than math during childhood (Stacy et al., 2017), and since myelination depends on neural activity, it is possible that more vs. less learning and associated neural activity affect myelination of specific white matter tracts, leading to differences such as those observed in SLF and AF tracts. In the context of evidence on aberrant anatomical and functional connectivity in ASD, and evidence on the role of different portions of SLF and AF tracts in reading and math, the findings from the present study, together with other recent findings on literacy and numeracy patterns in young autistic children, clear a path to novel, testable hypotheses on a possible role of aberrant brain connectivity in the variability in patterns of acquisition of these skills in autism.

Limitations and Future Research

While discerning a specific literacy-numeracy pattern in young children with ASD has theoretical and practical importance, the present study has some limitations. For example, given the comorbidities in children with ASD in our sample, it is possible that a clinically more homogenous picture (i.e., less variation in comorbidity) would lead to different results. Nevertheless, the finding that cognitively able children with ASD have word reading and spelling skills comparable to those found in typically developing children in the same age group, but worse numerical operations skills, further supports the notion that there exist different literacy-numeracy patterns in young children with autism. The important role of verbal IQ in numeracy skills observed in the present study indicates that developmental trajectories of these skills in ASD may depend on verbal abilities more than previously thought, requiring further research to determine specifically which verbal abilities are involved.

Another possible limitation of the study is that our sample contained considerably less girls than boys. Autism, like some other disorders, has a pervasive male bias, as it is four to five times more often diagnosed in boys than in girls (Baron-Cohen et al., 2011; McCarthy, 2016). Despite the higher rate of ASD in male individuals being recognized as one of the most consistent findings on the disorder (Halladay et al., 2015; Werling & Geschwind, 2013), this prevalence might also be the reason that many studies exclude female participants, which leaves an unclear picture on whether ASD affects literacy and numeracy in girls differently than in boys (Åsberg et al., 2010). This question is important, given the ongoing debate on cognitive sex differences and whether there exists a female advantage in verbal learning and a male advantage in math and spatial processing (e.g., Hyde, 2016; Kljajevic, 2022).

Future studies could explore these topics within a wider neurocognitive research framework, testing for possible sex differences in these domains in children with ASD and focusing on whether differences in connectivity patterns in SLF and AF contribute to the difference in acquisition of literacy and numeracy skills in autism.

Author Contribution VK is solely responsible for this work.

Data Availability All data are available at the Autism Brain Imaging Data Exchange (ABIDE II) database (http://fcon_1000.projects.nitrc.org).

Declarations

Ethics Approval Each site that contributed data to ABIDE II obtained ethics approval from their Institutional Review Board (IRB) (http://fcon_1000.projects.nitrc.org/indi/abide/abide_II.html).

Consent to Participate Using IRB-approved language and procedures, each site obtained written informed consent from a parent or guardian and child assent prior to data collection (http://fcon_1000.projects.nitrc.org/indi/abide/abide_II.html).

Conflict of Interest The author declares no competing interests.

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