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Academic achievement of children with autistic symptoms compared to typically developing children

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Abstract

Children with autistic symptoms experience challenges in school settings, yet little is known about their academic profiles and the mechanisms underlying the association between autistic symptoms and academic achievement. This study examined the association between autistic symptoms and academic achievement in a population-based sample of children with and without (sub)clinical autism spectrum disorder (ASD). We also investigated potential sex differences and assessed if the association is mediated by vocabulary skills and behavior problems. Information was available for 2038 participants (48.3% boys), and autistic symptoms were assessed using the Social Responsiveness Scale (M = 6.8 years). Diagnosis of ASD was clinically confirmed in 28 children. Academic achievement was determined by a nationwide, standardized test assessed at the end of primary school (M = 11.8 years). Children with more autistic symptoms in early childhood had lower achievement scores in language, mathematics, and world orientation by the end of primary education. There were no sex differences. Furthermore, vocabulary skills and behavior problems partly mediated the association between autistic symptoms and academic achievement. Then, by using propensity matching technique, we compared 140 matched typically developing peers with 28 children diagnosed with ASD. These results indicated no differences in academic achievement between children diagnosed with ASD and their matched typically developing peers. We conclude that autistic symptoms associate with lower academic achievement but by carefully matching on background variables and potential confounders, the academic achievement of children with clinical ASD might not differ from that of their typically developing peers.

Keywords Academic achievement · Autism spectrum disorder · Autistic symptoms · Propensity score matching · Vocabulary skills · Behavior problems

Autism spectrum disorder (ASD) is a neurodevelopmental disorder involving impairments in social interaction and communication (American Psychiatric Association, 2013). The process of diagnosing ASD involves multiple stages, beginning with initial screening and followed by behavior assessments, which can span from several weeks to several months

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(Crane et al., 2016). Children with ASD experience difficulties in the classroom, both academically and socially (Wei et al., 2015). Their difficulties include responding to social cues, such as greetings of their peers, and in understanding teacher instructions, particularly given their potentially limited vocabularies (Galinat et al., 2005). To explain these difficulties two, not necessarily incompatible, theories have been proposed: the "Theory of Mind" and "Executive Dysfunction." According to the "Theory of Mind" theory (Baron-Cohen, 2000), children with ASD struggle to attribute mental states such as intentions and emotions to themselves and others. The "Executive Dysfunction" theory (Fatima, 2019) proposes that children with ASD have difficulties with executive functions, such as planning and switching tasks, which can make schooling a challenging task for them.

Despite extensive research on the academic profiles of children with ASD (Butcher et al., 2009; Mayes & Calhoun, 2008; Whitby & Mancil, 2009), there has been relatively little research examining how autistic symptoms are related to academic achievement. Identifying mechanisms underlying the relation between autistic symptoms and academic achievement is important to inform early interventions. Specifically, although early language difficulties (Pickles et al., 2009) and behavior problems (Gray et al., 2012) have been reported as specific problems for children with ASD, little is known about the potentially mediating role of both early language difficulties and behavior problems in the association between autistic symptoms and later academic achievement.

The overall purpose of the present study is to extend our understanding of the association between autistic symptoms at an early age and academic achievement in early adolescence using a large population-based sample. Most available studies of children with ASD have been based on clinical case-control samples rather than population-based samples that might diverge in terms of their results. Population-based designs might also help in reducing the possibility of unmeasured confounders and recall bias.

Autistic symptoms and academic achievement

The severity of early autistic symptoms seems to be associated with later outcomes regarding employment, social relationships, physical and mental health, and quality of life (Ben-Itzchak & Zachor, 2007, 2020; Charman et al., 2003; Eaves & Ho, 2004; Howlin & Moss, 2012). Some studies have found that children with a history of autistic symptoms and with positive developmental outcomes at a later stage had milder symptoms and received more treatment at younger age (Fein et al., 2013; Pellicano, 2012). Relatedly, autistic symptoms severity seems to be negatively associated with IQ (Carter et al., 2007; Matson & Shoemaker, 2009; Perry et al., 2005). Other studies, however, suggest that it is impaired joint attention in early life, i.e., following eye gaze and identifying intention, that is crucial for cognitive development (Dawson et al., 2004; Morales et al., 2005), adaptive functioning (Eldevik et al., 2010; Makrygianni & Reed, 2010; Reichow, 2012; Thurm et al., 2007), and even parents' responsiveness to their children (Siller & Sigman, 2008).

In the literature, findings on academic achievement of children with ASD have been mixed. The varied results may be attributed to the use of different measures of academic achievement across studies and the specific aspects of academic performance that each study emphasizes. In a study by Chen et al. (2019), among 114 children with ASD (*M* = 6.8 years), autistic symptoms were not related to individual differences in academic skills, including mathematics achievement. Two reviews have reported that children with ASD are at risk of poor academic achievement (Howlin & Moss, 2012; Levy & Perry, 2011), whereas more recent studies suggested that children with ASD have a diverse profile of academic achievement, with some performing below and others above expected levels based on their IQ (Charman et al., 2011; Keen et al., 2016). Mayes and Calhoun (2003) have reported that the mathematics scores of children with ASD in their sample were within the expected range, only 22% had a specific learning disability in mathematics. Miller et al. (2017) found that children with ASD demonstrated a weakness in reading comprehension relative to word reading ability. However, most of these studies have used clinically ascertained samples whereas there is limited evidence for the whole range from sub-clinical ASD to the full spectrum of ASD. Therefore, in the present study, we aim to fill this gap in knowledge by studying the longitudinal association between autistic symptoms and academic achievement in a population-based sample. Specifically, our study will concentrate on a standardized educational assessment that is used in the Netherlands to measure academic abilities and knowledge and evaluate the educational progress of students in various subjects (mathematics, language, and world orientation).

ASD is more common in boys than girls, with a ratio of approximately four to one (Baird et al., 2006; Loomes et al., 2017). Carter et al. (2007) have found that boys with ASD attained higher language and motor scores and higher social competence ratings than girls. However, other studies found no sex differences for either verbal or performance IQ (Mandy et al., 2012) nor for visual reception, fine motor skill performance, and language skills (Hartley & Sikora, 2009). Given this variability in findings, it is important to take sex differences into account, as studying boys and girls together may have masked associations between ASD symptoms and academic achievements in either group.

Vocabulary skills and behavior problems

In order to develop early intervention programs, understanding mechanisms leading from early autistic symptoms to later academic achievement is important. Accordingly, we focus on vocabulary skills and behavior problems as two possible mechanisms underlying the association of ASD with poorer academic achievement. Many children with ASD encounter challenges in language abilities and behavioral issues, and these difficulties could even be interconnected. For example, Park et al. (2012) have reported that in preschool-aged children with ASD, receptive language skills are associated with particular types of behavior problems (i.e., self-absorbed behavior and social relating). With regard to vocabulary skills, early language difficulties are among the reasons why parents have had their children screened for ASD (Tager-Flusberg & Caronna, 2007). Vocabulary is fundamental to language development and serves as a foundation for further learning in reading, writing, and comprehension (Alqahtani, 2015). In other words, a strong vocabulary base can facilitate the acquisition of new knowledge and enhance understanding across various subjects. At 3 years of age, 50% of children with ASD have not developed meaningful words (Tager-Flusberg & Kasari, 2013), and despite early interventions, language impairments persist in about 30% of children with ASD (Anderson et al., 2007). Indeed, language skills is an important predictor of academic achievement in children with ASD (Howlin et al., 2004; Volkmar et al., 2004). Children with ASD, who are significantly delayed in their language development at a young age, continue to show poor linguistic skills (Szatmari et al., 2003).

Second, the association between autistic symptoms and academic achievement may be mediated by behavior problems. The majority of individuals with ASD have behavior or learning problems (Niklasson et al., 2009), and children with ASD have more behavior problems compared to children with other intellectual disabilities (De Clercq et al., 2019;

Kasari & Sigman, 1997). At the same time, behavior problems, particularly externalizing and attention problems, are related to poorer academic achievement (Nelson et al., 2004; Polderman et al., 2010). Despite initial research reporting empirical evidence for predictive relations between vocabulary skills and behavior problems to later school achievement, to the best of our knowledge, no research has yet examined both vocabulary skills and behavior problems as potential mediators of the association between autistic symptoms and academic achievement.

We recognize that terminology preferences within the autism research field can vary. To ensure consistency throughout this paper, we use the term "clinical ASD" to refer to children who have received a formal clinical diagnosis of ASD. The term "sub-clinical ASD" represents children who have not been clinically diagnosed with ASD but may exhibit a relatively high level of autistic symptoms. Throughout the paper, we use the term "autistic symptoms" to encompass all potential symptoms associated with ASD.

Research questions

Both clinicians and researchers agree that children with autistic symptoms experience academic challenges in the school settings (Assouline et al., 2012). Yet, we know little about the academic profiles of children with autistic symptoms and about the mechanisms underlying this association (Kim et al., 2018), while such knowledge is important for early screening and the use of early interventions aimed at improving academic achievement (Billstedt et al., 2005; Howlin, 2000). In the current study, therefore, we investigated academic achievement in a large population-based cohort of children (*M* = 11.8 years, *SD* = 0.4), including boys and girls with and without (sub)clinical ASD. First, we tested the association between autistic symptoms and academic achievement (language, mathematics, and world orientation) in the whole sample and investigated sex differences. Second, we assessed whether the association between autistic symptoms and academic achievement is mediated by vocabulary skills and by behavior problems. Third, we examined if the association is replicated in children clinically diagnosed with ASD by comparing these children to matched typically developing children, using a propensity score matching technique.

Methods

Study design

The study was embedded in the Generation R Study, a population-based cohort from fetal life onward in Rotterdam, the Netherlands (Kooijman et al., 2016). Briefly, the Generation R Study was designed to identify early environmental and genetic causes of normal and abnormal growth, development, and health from fetal life until young adulthood (Jaddoe et al., 2007). The children are part of a prenatally recruited birth cohort that will be followed until young adulthood. Assessment waves were annually in the preschool period (0–4 years), followed by assessment waves at ages 6 and 10 years. Data were collected through home visits, repeated questionnaires, and routine child health center visits. For the current study, we used parent-reported questionnaire data on autistic symptoms collected when the children were 6 years of age (*M* = 6.8 years, *SD* =0.4). Vocabulary skills were assessed using an age-appropriate receptive subtest of a Dutch test battery (see below).

Behavior problems were assessed at 9/10 years of age using the Child Behavior Checklist (CBCL/6–18, M = 9.7, SD = 0.3). Furthermore, information from general practitioners have been collected to ascertain the ASD diagnosis (Kooijman et al., 2016). School achievement was assessed at 12 years with the standardized CITO test (M =11.8, SD = 0.4). The study was approved by the institutional review board of the Erasmus Medical Centre. Written consent was obtained from caregivers.

Participants

A total of 9778 mothers enrolled in the study, of whom 8878 (91%) enrolled during pregnancy. The expected delivery date of the pregnant women was between April 2002 and January 2006. Consent for the current study was available for n = 5444 children. Participants with missing data on autistic symptoms (n = 1378) were excluded. Participants who did not consent to the use of their academic achievement test (n = 1253) or had missing data on the test (n = 775) were also excluded, resulting in a final sample size of n = 2038. Figure 1 shows the participant flowchart, and Table 1 presents the baseline characteristics of the study sample.

Measures

Autistic symptoms

Autistic symptoms were measured using the Social Responsiveness Scale (SRS; Constantino & Gruber, 2002). The SRS is a widely used quantitative screening tool for autistic symptoms, and it measures the severity of autistic symptoms in the general population. To minimize subject burden, we employed the SRS short form (18 items). The items were selected based on conceptual importance and item relevance, leading to the retention of items that are most pertinent to ASD. The SRS short form covers three domains: social communication, social cognition, and autistic mannerism (see the 18 items in previous Generation R publications (Román et al., 2013; Sari et al., 2021). The SRS is an assessment of autistic symptoms in a naturalistic setting (Constantino & Gruber, 2002). Parents of the children filled out the questionnaire when the children were 6 years of age (M = 6.8 years, SD =0.4). Parents were asked to rate probes on a 4-point Likert scale; 0 (*not true*); 1 (*sometimes true*); 2 (*often true*); and 3 (*almost always true*), e.g., "My child has repetitive, odd behaviors such as hand flapping or rocking". The SRS short form, as used in the Generation R sample, is highly correlated (r = .95) with the full 65-item version (Blanken et al., 2015; Román et al., 2013; Serdarevic et al., 2017). Internal consistency was estimated for males and females separately (Cronbach's α for both males and females: .92).

ASD diagnosis

To obtain information on ASD diagnosis, a multiple-gating procedure was used (Serdarevic et al., 2017). Children's medical records maintained by general practitioners were searched for children who (a) had a high score on the SRS short form, (b) had a positive score on the Social Communication Questionnaire (SCQ; Berument et al., 1999), which was only administered for children who scored in the top 15th percentile on the Child Behavior Check List (CBCL/1.5-5) total score or those in the 2nd percentile on the Pervasive Developmental Problems Score of the CBCL, or (c) had been assessed for ASD according to

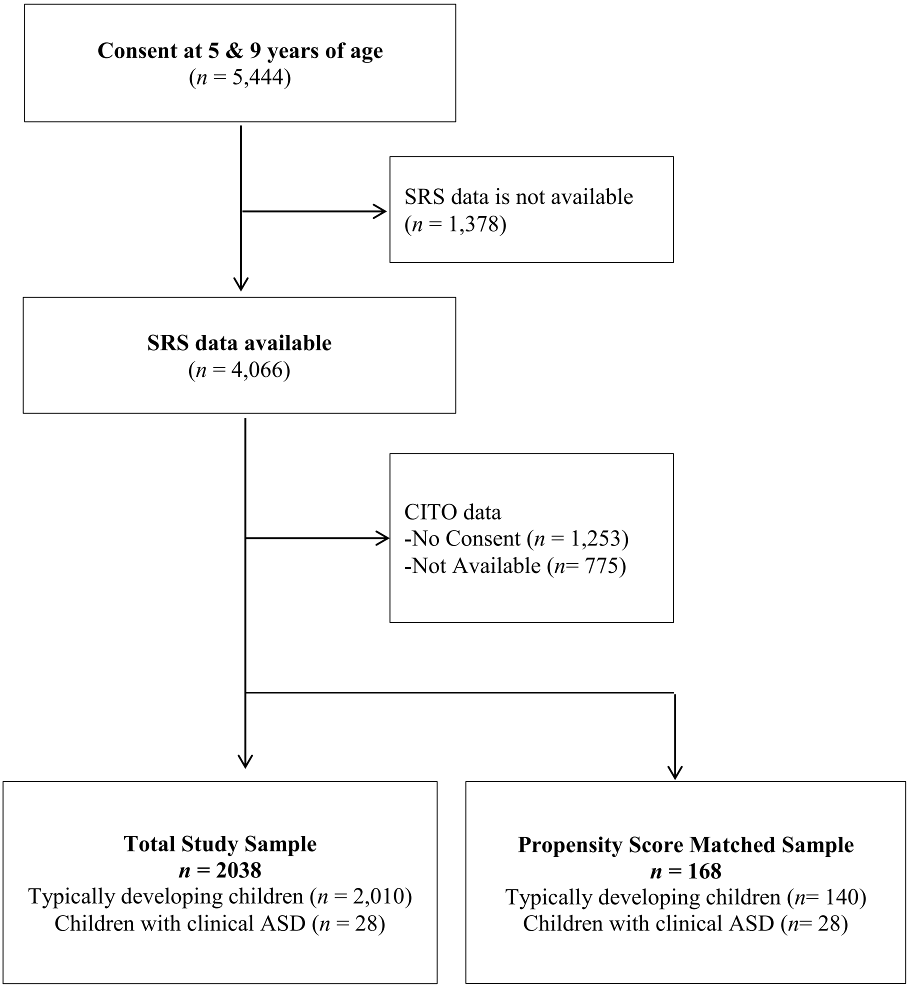

Fig. 1 Flow chart of participants included for analyses

parental report. Only children for whom a diagnosis of ASD was confirmed by these medical records were considered ASD cases in the analyses. The specialist diagnoses of ASD were generally based on clinical consensus by a multidisciplinary team. The standard diagnostic work-up involves an extensive developmental case history obtained from parents as well as school information and repeated observations of the child (Serdarevic et al., 2017).

Academic achievement

Academic achievement was measured using a standardized school achievement test of the Central Institute for Test Development (CITO). The CITO test is used by approximately 77% of the primary schools nationwide as a standardized measure of academic performance in the Netherlands to inform parents and teachers about the most suitable type of secondary education. CITO test assesses different areas including language, mathematics,

Table 1 Participant characteristics (*n*= 2038)

Characteristics	*n*	Total study sample *n* = 2038	Typically developing *n* = 140	Clinical ASD *n* = 28
Maternal				
Age (years)	2038	31.8 (4.3)	31.5 (4.2)	31.8 (3.8)
Education (%)				
High	1329	65.2	51.4	64.3
Mid	511	25.1	37.9	25.0
Low	141	6.9	10.7	7.1
Family income (%)				
>2000 euros	1779	87.3	88.6	89.3
<2000 euros	259	12.7	11.4	10.7
Marital status (%)				
Married/living together	1016	49.9	53.6	57.1
Unmarried	920	45.1	42.9	39.3
Depression Score	1869	0.9 (2.0)	1.4 (2.5)	1.5 (2.6)
Autism Quotient Score	1633	50.4 (8.7)	48.4 (8.6)	48.3 (10.5)
Child				
Gestational age (weeks)	2023	39.8 (1.9)	40.4 (1.4)	40.3 (1.4)
Sex (%)				
Boy	985	48.3	83.6	89.3
Girl	1053	51.7	16.4	10.7
Birth weight (grams)	2038	3461.7 (577.3)	3677.8 (471.1)	3624.6 (474.9)
Ethnicity (%)				
Dutch	1457	71.5	80.7	78.6
Non-Dutch	581	28.5	19.3	21.4
Nonverbal IQ	1811	105.1 (14.0)	105.3 (14.5)	103.7 (15.2)
Total problems at 10 years (CBCL)	1884	16.2 (14.3)	16.1 (14.4)*	38.7 (23.5)*
Vocabulary skills (TvK)	1703	22.7 (2.6)	22.7 (2.6)	22.5 (3.3)
Autistic symptoms (SRS)	2038	3.6 (3.5)	3.7 (3.6)*	14.3 (9.4)*
Academic achievement (CITO)				
Age at test	2038	11.8 (0.4)	11.8 (0.4)	11.8 (0.4)
Language score	2038	102.4 (17.1)	100.4 (17.7)	102.4 (16.6)
Mathematics score	2038	62.1 (14.4)	62.7 (14.2)	61.4 (14.8)
World orientation score	1266	66.2 (11.3)	65.3 (12.6)	66.4 (13.4)
Total score	2038	539.3 (8.7)	538.42 (8.8)	540.3 (7.9)

Data represent means (SDs) unless specified otherwise. *CBCL* Child Behavior Checklist, *SRS* Social Responsiveness Scale, *TvK* Taaltest voor Kinderen, *CITO* Centraal Instituut voor Toets Ontwikkeling. Missing data: 2.8% maternal education, 5% marital status. *$p < .05$ for comparison between propensity score matched sample of typically developing versus children with clinical ASD

and world orientation, the latter is optional. The correlations among these subtests are medium (see Supplementary Table 3). The language subtests included tests of writing (30 items), spelling of verbs (10 items), spelling (all other than verbs, 10 items), reading comprehension (30 items), and vocabulary (20 items). Example questions addressed in this test are "What does the word 'fortress' mean?," and "Which of the following words is past tense?" The mathematics subtests include numbers and mental arithmetic (25 items); proportions, fractions, and percentages (20 items); and geometry, money, and time (15 items). An example question is "Pete buys 15 books. The costs are 4.95 per book. What are the total costs?." The world orientation subtest includes geography (30 items), history (30 items), and biology (30 items). An example question is "Which of the following sentences describes a solar system?" The high number of participants (n = 722) without information on world orientation can be explained by the fact that this subtest is optional for schools. Yet, the world orientation subtest can offer valuable insights into children's skills, particularly in terms of general knowledge related to geography, history, and biology, which are part of the school curriculum. World orientation taps into crystallized intelligence as the accumulated knowledge of facts and skills important for later social, civic, and work-related adaptation.

The CITO test is used by approximately 85% of all Dutch primary schools (Lubbe, n.d.). Reliability of CITO scores are good to excellent, with Cronbach's α for the complete test α = .91, and for the subtests, mathematics α = .91, language α = .83, and world orientation α = 80. This test is administered in the final year of primary school, usually around age 12 years. In this standardized test, the score ranges are as follows: 39 to 134 for the language subscale, 11 to 85 for mathematics, and 17 to 89 for world orientation. The score for the overall CITO test in the Netherlands ranges from 501 to 550.

Confounders

Based on the literature, several variables were considered as possible confounders in the association between autistic symptoms and academic achievement. Maternal age, educational level, family income, and marital status were obtained at enrolment using self-report questionnaires. Maternal education, defined by the highest attained education, was divided into the following: low education, consisting of no education and primary school only; medium education, which included secondary school level; high education, including higher vocational training and university level. Monthly family income was categorized into two categories: less than 2500 euros and more than 2500 euros per month. Marital status was dichotomized into "married" and "unmarried." Nonverbal IQ of the mother was assessed during the visit to the research centre at the child's age of 6 years using a computerized version of the Ravens Advanced Progressive Matrices Test, set I (Prieler, 2003). Maternal depressive symptoms were assessed with the Brief Symptom Inventory (BSI), a short version of the Symptom Checklist 90 (SCL-90) (de Beurs & Zitman, 2005; Derogatis, 1993). Maternal autistic symptoms were obtained using the Autism Spectrum Quotient (AQ-Short) (Hoekstra et al., 2011). Information on sex, birth weight, and gestational age of the child was obtained from the medical records completed by community midwives and obstetricians at birth. The child's ethnicity was classified by the countries of birth of the parents, according to the Dutch Standard Classification Criteria of Statistics Netherlands (Statistics Netherlands, 2004).

Mediators vocabulary skills and behavior problems

Vocabulary skills were assessed at age 7 years using an age-appropriate receptive subtest of a Dutch test battery: Taaltest Voor Kinderen (Language Test for Children; van Bon, 1982). To reduce the burden for children, 27 items were selected from the full battery consisting of 40 items (Ghassabian et al., 2014). By choosing the correct alternative from two pictures that matched a given word, information about children's vocabulary comprehension skills was obtained. Correct answers were summed and divided by the number of items answered, yielding a corrected percentage score (Ghassabian et al., 2014). The internal consistency for this shortened test in our sample was moderate, Cronbach α = .68 (Luijk et al., 2015).

Behavior problems were assessed at 9/10 years of age using the Child Behavior Checklist (CBCL/6-18; Achenbach & Rescorla, 2000), a parent report questionnaire. This questionnaire measures empirically based scales that were derived by factor analyses: anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, and aggressive behavior. The "Total problems score" is the sum score of all items. Good reliability and validity have been reported for the CBCL (Achenbach & Rescorla, 2000), and within this study sample, Cronbach's alphas for the total score was found to be reliable (112 items; α = .78).

Statistical analyses

All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS, v. 24). Non-response analyses were conducted to examine the differences between the participants who dropped out versus those who remained in the study. Understanding such differences can aid in determining the generalizability of the study's findings. In this study, we performed three sets of analyses. The first set of analyses tested the association between autistic symptoms and academic achievement (language, mathematics, and world orientation) in the whole sample and investigated sex differences. The second set of analyses assessed whether the association between autistic symptoms and academic achievement is mediated by vocabulary skills and by behavior problems. The third set of analyses replicated the first analyses by comparing children diagnosed with ASD with their matched typically developing peers.

In the first set of analyses, the total study sample was used to assess the association between autistic symptoms and academic achievement. Three linear regression analyses were performed: one for language, one for mathematics, and one for world orientation scores. We constructed three models for the analyses. These models were constructed by clustering of potential confounding factors, i.e., child and maternal characteristics. The first model was unadjusted. In the second model, child sex, birth weight, and age at CITO test were included. In the third model, we additionally adjusted for the following maternal confounders: educational level, maternal IQ, depressive symptoms, and autism spectrum quotient, as confounders were only added in the model if they changed the effect estimates by more than 5%. Maternal age, family income, marital status, maternal ethnicity, gestational age at birth, and child ethnicity were therefore not included in the final model. The independent (SRS score) and dependent variables (CITO scores) were standardized into z-scores for ease of comparison over the different instruments and time points. In addition, a sensitivity analysis was performed by including child nonverbal IQ into the model to check whether the results remained the same.

For missing data on confounders, multiple imputation was used. Twenty independent datasets were generated, and pooled estimates were calculated. The confounders with missing values were maternal autism quotient (19.9%), maternal depression (8.3%), maternal IQ (7.6%), behavior problems (7.6%), and maternal education (2.8%). These data were missing completely at random tested by Little's MCAR test (χ^2 (27) = 39.4, p = .06).

Additionally, we bootstrapped to ensure that the outcome is within the confidence interval of 95%. In addition, we tested for a potential interaction effect of sex.

In the second set of analyses, a mediation model was tested in the total study sample with both vocabulary skills and behavior problems as mediators of the association between autistic symptoms and academic achievement, using PROCESS (Hayes, 2012). PROCESS is a linear regression path analyses modelling tool for SPSS. The parameter estimates were calculated by pooling the results of 20 imputed datasets (with Excel). The mediation model was run with 95% bias-corrected bootstrap confidence interval applying 5000 bootstrap samples using case resampling with replacement in every imputed dataset. Moreover, a sensitivity analysis was conducted because the total behavior problems questionnaire includes items that overlap with the autistic symptoms questionnaire (Ooi et al., 2011; So et al., 2013).

In the third set of analyses, we compared children with clinical ASD to typically developing children. To do so, we created a propensity score matched dataset using a propensity score matching technique. This technique matches children with clinical ASD to typically developing children based on measured covariates (Thoemmes, 2012). Previous studies have used this technique and showed that it can effectively balance the covariates (Heinrich et al., n.d.; Thomas et al., 2020). In this study, the covariates chosen for propensity matching included both child and maternal characteristics, as covariates of convenience (e.g., sex, age) are usually not sufficient (Shadish et al., 2008) for proper estimation of the propensity score. They were child sex, ethnicity, birth weight, gestational age, as well as parents' education, income, maternal IQ, autism spectrum quotient, and depression score. The analysis was performed by using an additional package of custom dialog "psmatching" that works in SPSS version 24. The "psmatching" performs all analyses in R through the SPSS R-Plugin. We used the matching algorithm of nearest neighbor matching, a routine to match each unit sequentially to a unit in the control group that has the closest propensity score. We specified matching without replacement to avoid a child in the control group being matched and used twice. We calculated how many matched typically developing children were needed assuming a moderate effect size of Cohen's $d = 0.50$ by using G*Power (Faul et al., 2007) We set the available 28 children with clinical ASD as sample baseline. The analysis indicated a sample size of $n = 140$ children in the matched sample of typically developing children was needed. Therefore, the ratio matching was specified to be 1:5. *T*-tests were used to examine the mean differences on academic achievement scores.

Results

Descriptive statistics

The characteristics of the mothers and their children are summarized in Table 1. We displayed the descriptive statistics for the total study sample ($n = 2038$), the subset of children with clinical ASD ($n = 28$), and the propensity score matched typically developing children ($n = 140$). In the total study sample, 65.2% of the mothers attained a high educational level. Seventy-one percent of the children were of non-immigrant Dutch background. Among the children with clinical ASD, the proportion of boys was higher than girls: 89.3% were boys, and 10.7% were girls. This sex proportion was similar in the matched typically developing children. However, total behavior problems and autistic symptoms score was significantly higher in children with clinical ASD ($M_{\text{autistic symptoms score}} = 14.3$, $SD = 9.4$) than in matched typically developing children ($M_{\text{autistic symptoms score}} = 3.7$, $SD = 3.6$) with the effect size Hedges' $g = 2.1$. We also examined whether the respondents who were excluded ($n = 3406$) differed from those included in the study sample ($n = 2038$). Some differences were found. Mothers who were excluded were younger ($M = 30.5$ years, $SD = 5.1$ vs $M = 31.8$ years, $SD = 4.3$, $t\,(5442) = 9.2$, $p = <.01$), lower educated (12.7% vs 6.9% low educated, $p < .01$), had lower family income (18.9% vs 12.7% income below 2000 euros, $p < .01$), and their children were more often of non-Dutch ethnicity (46% vs 28.5%, $p < .01$).

In the total study sample, the CITO subscale scores (language, mathematics, and world orientation) were significantly correlated with vocabulary skills and behavior problems. Vocabulary skills and the three subscales of academic achievement were positively correlated ($r = .27$ for language, $r = .21$ for mathematics, $r = .34$ for world orientation). Behavior problems correlated negatively with academic achievement ($r = -.15$ for language, $r = -.13$ for mathematics, $r = -.14$ for world orientation).

Multiple linear regression analyses

In the total study sample, more autistic symptoms predicted lower language achievement ($\beta = -.170$, $p < .01$, Table 2). This association attenuated but remained statistically significant in the fully adjusted model ($\beta = -.088$, $p <.01$, Table 2). Similar results were found in the fully adjusted model for the association of autistic symptoms with mathematics achievement ($\beta = -.064$, $p <.01$, Table 3) and world orientation achievement ($\beta = -.108$, $p <.01$, Table 4). No significant interaction effects of sex on the association between autistic symptoms and the three subscales of academic achievement were found (see supplementary Figure 1).

A sensitivity analysis was conducted by including child nonverbal IQ into the model: the results remained essentially the same, with autistic symptoms predicting poorer language ($\beta = -.079$, $p <.01$), mathematics ($\beta = -.054$, $p <.01$), and world orientation achievements ($\beta = -.088$, $p <.01$) (see supplementary Table 1).

Mediation analyses

Results of the mediation analyses indicated that vocabulary skills and behavior problems were significant mediators: partial mediation was found between autistic symptoms and language achievement ($\beta_{\text{indirect effect}} = -.042$, 95% CI $-.061$; $-.028$), mathematics achievement ($\beta_{\text{indirect effect}} = -.038$, 95% CI $-.062$; $-.029$), and world orientation achievement ($\beta_{\text{indirect effect}} = -.046$, 95% CI $-.067$; $-.025$) (Fig. 3).

A sensitivity analysis was conducted because the total behavior problems questionnaire includes items that overlap with the autistic symptoms' questionnaire, as also reflected in the correlation between the two questionnaires ($r = .33$, $p <.01$). Therefore, we reran the mediation analyses after excluding nine overlapping items from the total behavior problems questionnaire (So et al., 2013). The results of the mediation analyses were similar (see supplementary Table 2).

Propensity score matched analyses

We presented characteristics of the matched sample before and after propensity score matching in Supplementary Table 4. Before propensity score matching, the samples of

Table 2 Association between autistic symptoms and language achievement (n= 2038)

	Model 1[a]			Model 2[b]			Model 3[c]		
	β (95% CI)		p	β (95% CI)	p		β (95% CI)		p
Step 1[a]									
Autistic symptoms	−.170	(−.213; −.127)	.000	−.158	(−.201; −.115)	.000	−.088	(−.131; −.044)	.000
Step 2[b]									
Sex				.069	(.026; .113)	.002	.075	(.033; .116)	.000
Birth Weight				.081	(.038; .124)	.000	.043	(.002; .085)	.040
Age at test				−.015	(−.058; .027)	.480	.026	(−.015; .067)	.216
Step 3[c]									
Maternal education							.211	(.163; .259)	.000
Maternal IQ							.145	(.098; .192)	.000
Maternal depression							.013	(−.030; .056)	.548
Maternal autism quotient							−.044	(−.093; .005)	.081

β standardized beta, *95% CI* 95% confidence interval

[a]Unadjusted analysis

[b]Adjusted for children characteristics: sex, birth weight, and age at taking language test

[c]Adjusted for maternal characteristics: education level, intelligent quotient, depression score, autism spectrum quotient

Table 3 Association between autistic symptoms and mathematics achievement (n= 2038)

	Model 1[a]			Model 2[b]			Model 3[c]		
	β (95% CI)		p	β (95% CI)		p	β (95% CI)		p
Step 1									
Autistic symptoms	−.109	(−.152; −.066)	.000	−.125	(−.169; −.082)	.000	−.064	(−.107; −.020)	.004
Step 2									
Sex				−.111	(−.154; −.067)	.000	−.107	(−.149; −.065)	.000
Birth weight				.092	(.048; .135)	.000	.057	(.015; .098)	.008
Age at test				−.028	(−.070; .015)	.209	.013	(−.028; .055)	.523
Step 3									
Maternal education							.189	(.139; .238)	.000
Maternal IQ							.168	(.121; .216)	.000
Maternal depression							.002	(−.041; .045)	.921
Maternal autism quotient							−.008	(−.057; .041)	.751

β standardized beta, *95% CI* 95% confidence interval

[a]Unadjusted analysis

[b]Adjusted for children characteristics: sex, birth weight, and age at taking mathematics test

[c]Adjusted for maternal characteristics: education level, intelligent quotient, depression score, autism spectrum quotient

Table 4 Association between autistic symptoms and world orientation ($n = 1266$)

	Model 1[a]			Model 2[b]			Model 3[c]		
	β (95% CI)		p	β (95% CI)		p	β (95% CI)		p
Step 1									
Autistic symptoms	−.143	(−.198; −.088)	.000	−.171	(−.226; −.116)	.000	−.108	(−.161; −.054)	.000
Step 2									
Sex				−.148	(−.202; −.093)	.000	−.157	(−.209; −.106)	.000
Birth weight				.088	(.034; .143)	.001	.045	(−.006; .097)	.085
Age at test				−.104	(−.158; −.050)	.000	−.065	(−.115; −.014)	.013
Step 3									
Maternal education							.254	(.193; .315)	.000
Maternal IQ							.173	(.111; .234)	.000
Maternal depression							−.034	(−.088; .020)	.217
Maternal autism quotient							−.001	(−.058; .057)	.975

β standardized beta, *95% CI* 95% confidence interval

[a]Unadjusted analysis

[b]Adjusted for children characteristics: sex, birth weight, and age at taking world orientation test

[c]Adjusted for maternal characteristics: education level, intelligent quotient, depression score, autism spectrum quotient

children with clinical ASD and matched typically developing children differed on two covariates, i.e., maternal depression (M = 0.2, SD = 0.3 vs M = 1.5, SD = 2.6, $t(158) = -1.5$, $p < .01$) and sex (52.1 % vs 89.3 % boys, $p < 0.1$). After propensity score matching, the groups did not differ anymore on these covariates.

In the propensity score matched sample, an independent samples t-test was conducted to compare the three subscales of academic achievement in children with and without (sub) clinical ASD. Figure 2 indicates no differences between children with and without (sub) clinical ASD, neither for language (t (166) = −.54, p = .59), mathematics (t (166) = .42, p = .68), or world orientation (t (166) = −.35, p = .72).

As indicated in the methods, the sample size of n =168 for our matched sample (corresponding to a 1:5 ratio) should have been sufficient to detect a moderate effect. However, the effect size found in the total study sample (β = .088; a small effect) combined with alpha 0.05 and power of 0.80 resulted in a minimum required sample of 300 children in the propensity score matched group to detect this effect. Therefore, we additionally performed an analysis using a matching ratio of 1:10 in the propensity score matching (n_{total} = 280). This approach replicated the null findings of the original propensity score matched analysis.

Discussion

This is the first population-based cohort study examining autistic symptoms in early childhood and its association with academic achievement in early adolescence. Increased autistic symptoms in early childhood predicted poorer academic achievement in language, mathematics, and world orientation at age 12 years. Vocabulary skills and behavior problems in middle childhood mediated the relation between the autistic symptoms and academic

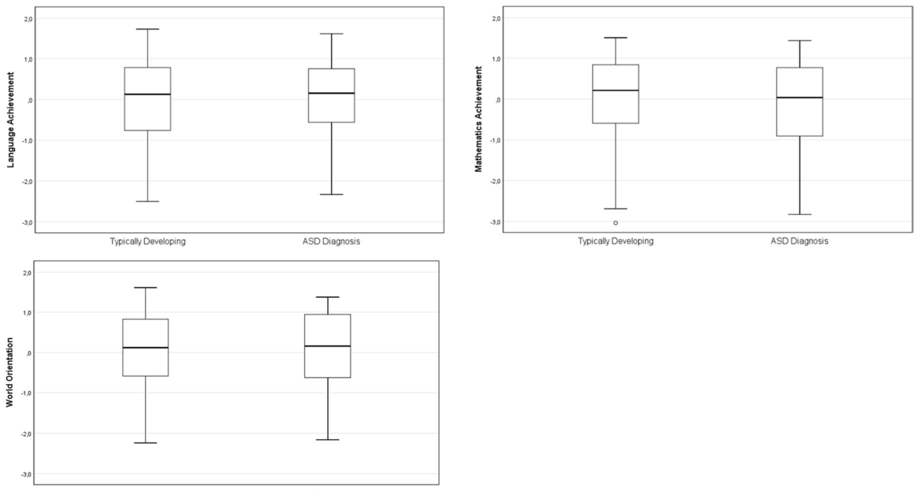

Fig. 2 Academic achievement difference of children with clinical ASD versus matched typically developing peers (n = 168). Boxplot showing median, interquartile range, minimum, and maximum duration in propensity score matched sample in the subscale academic achievements: language, mathematics, and world orientation

achievement. However, when we carefully matched children with clinical ASD to typically developing children, the differences in academic achievement disappeared.

Showing autistic symptoms was associated with lower performance in all three academic domains. This result is consistent to previous studies indicating that autistic symptoms were negatively related to language performance (McIntyre et al., 2017; Ricketts et al., 2013; Solari et al., 2019; Wei et al., 2015) and world orientation (Levy & Perry, 2011). Findings for mathematics have been mixed: the results of our study support the work of Oswald et al. (2016) in which 22% of the clinical ASD sample evidenced a mathematics learning disability, while only 4% exhibited mathematical giftedness, autistic symptoms contributed to the variance in mathematics achievement of adolescents. However, in another study with children aged 7 to 12 years (Chen et al., 2019), mathematics achievement and autistic symptoms were unrelated.

The association between autistic symptoms and academic achievement was mediated by vocabulary skills and behavior problems. Indeed, lower vocabulary skills (Assouline et al., 2012) and behavior problems (Henricsson & Rydell, 2006; Jimerson et al., 2000; McClelland et al., 2000) separately have been related to lower academic achievement. None of these previous studies examined both vocabulary skills and behavior problems in one model. Together, both vocabulary skills and behavior problems partly mediated the relation between autistic symptoms and academic achievement (Fig. 3).

Propensity score matched sample

Results from our second approach showed that there were no differences on academic achievement between children with clinical ASD and their matched typically developing peers in all of the three domains: language, mathematics, and world orientation. This result supports previous studies that children with clinical ASD may improve their language ability over time (Stevens et al., 2000; Turner et al., 2006) and may have preserved, or even gifted, skills in the domain of mathematics (Assouline et al., 2012; Cash, 1999; Zajic et al., 2018).

In a study of children with clinical ASD, children with clinical ASD *and* hyperlexia performed as well as typically developing children on all reading-related tasks other than reading comprehension (Newman et al., 2007). Another study by Helt and colleagues suggested that 3–25% of individuals with clinical ASD fall within the average range cognitively and adaptively, and are functioning independently in the community (Helt et al., 2008). A study by Howlin (2003) mentioned that when children with autistic symptoms become more aware of their differences, they begin to make an effort to adapt their behavior which might explain how children with clinical ASD are able to catch up with typically developing children.

The majority of children diagnosed with clinical ASD in this study had nonverbal IQ ranging from 78 to 140; therefore, they were able to spend most of their instructional time in general education settings. The implication is that they had more access to their typically developing peers which might be a benefit given that typically developing peers can serve as role models for academic development (Justice et al., 2014). Our result supports the study by Kim et al. (2018) showing that children with clinical ASD who remained in a general education setting had significantly higher academic achievement and lower autistic symptoms severity compared with those who moved to special education classrooms, independently of their IQ.

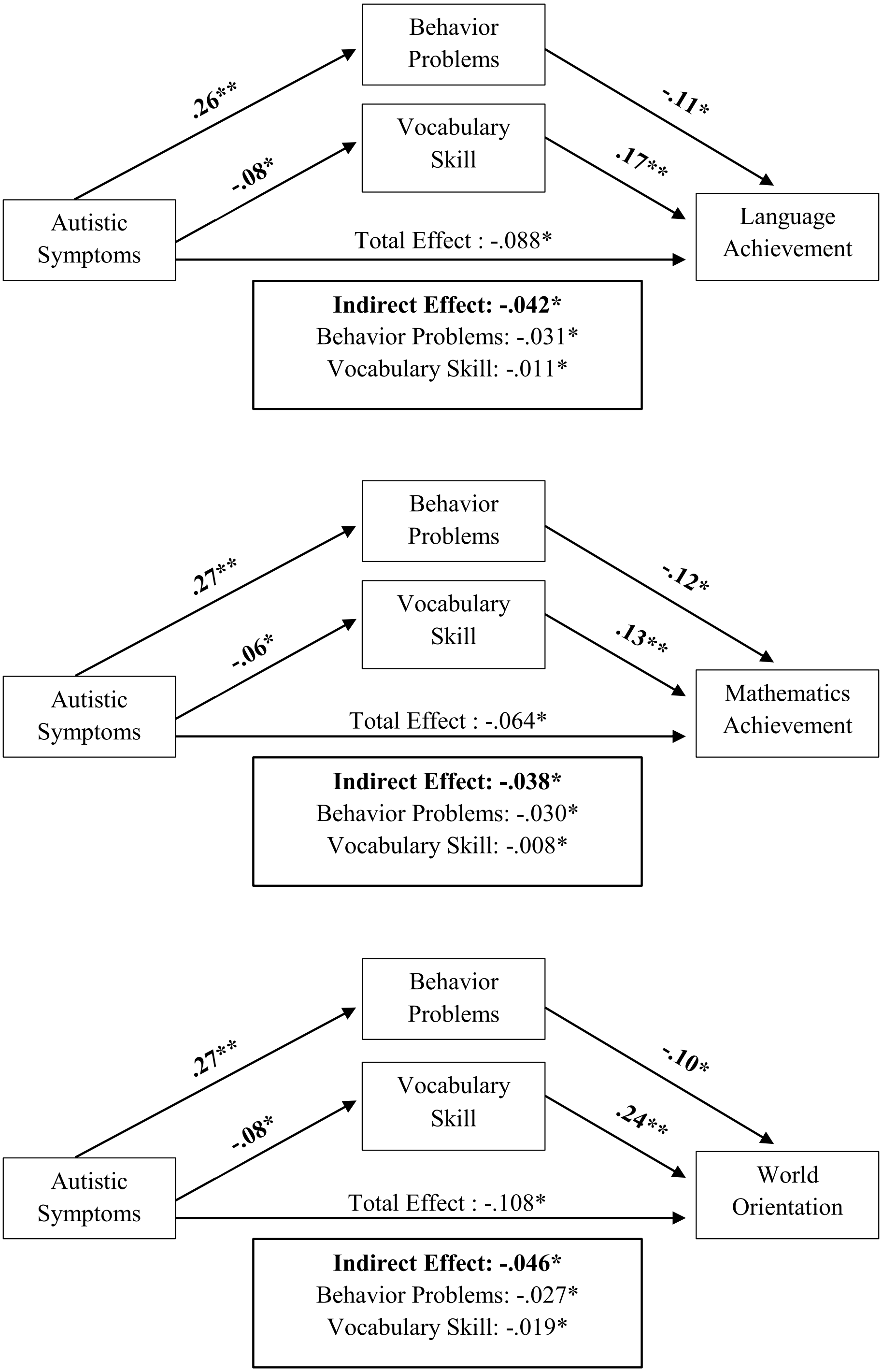

Fig. 3 Relationship between autistic symptoms and academic achievement as mediated by behavior problems and vocabulary skills

We wanted to create a typically developing group with similar background characteristics as children with clinical ASD, and matched the groups on the covariates, but not on determinant or outcome measures. The finding that the levels of autistic symptoms were higher in the clinical ASD sample than in the matched sample implies that the SRS is a reliable tool (Bölte et al., 2008) to screen and identify children with autistic symptoms.

Furthermore, the effect size of autistic symptoms on academic achievement in our total study sample was relatively small which leaves room for children with elevated levels of autistic symptoms to perform equally well as their typically developing peers. The reason why we could not detect any differences between the matched groups might also be associated with the relatively limited sample size. The current study includes the matched typically developing children group for comparison with children with clinical ASD so that we were able to control for a large variety of potential confounders. Although this is a notable feature of this study, the small number of clinical ASD could only partly be compensated by the propensity score matching. The relatively small effect sizes of the large cohort might have been difficult to detect in the matched sample, although we showed that in a larger propensity score matched sample with sufficient power, no effect could be observed either.

The first set of analyses showed that autistic symptoms were associated with lower academic achievement. A mechanism underlying the association of autistic symptoms and lower academic achievement was shown in the second set of analyses; vocabulary skills and behavior problems partly mediated the association. Finally, the third set of analyses examined whether the results replicated in a clinical ASD sub-sample, which was not the case. This latter result contrasts with the findings in the total cohort. Potentially, the group of clinically diagnosed autistic children may function differently in school compared to their peers with less severe autism symptoms. Of course, this might also be interpreted as a measurement issue that treats clinically diagnosed autism simply as an extreme part of a basically continuous distribution of autism symptoms. In reality, children with a clinical diagnosis may be a qualitatively separate class of children with a fundamentally different profile that entails a critical mass of features specifically impacting school performance in different ways compared to the rest of the continuum. This result creates an intriguing question for future research on the differences between population-based studies and clinical samples.

Limitations

When interpreting the results of this study, one should take into account of a number of limitations. First, our study was conducted in a Dutch, urban population, which limits the generalizability of our results. However, this is actually a large population-based cohort study that has a major advantage in terms of the possibility to study multiple exposures and outcomes (Euser et al., 2009). A second limitation is that the sample consisted of a relatively high socioeconomic background. This selective response may, however, not have had substantial effects on the associations reported here (Nilsen et al., 2009). The third limitation is that the results of this study were based on children with clinical ASD who were able to take standardized assessment; therefore, their academic achievement was likely to be higher than that of the population of children with clinical ASD. Despite these limitations, our findings represent one of the few studies with an objective measure of academic achievement and comprising not only children with autistic symptoms screened by the SRS but also children with clinical ASD.

Future directions and implications

From an educational perspective, our results show that children with clinical ASD and an IQ in the typical range might be able to perform similarly to typically developing children in regular classrooms. Furthermore, we found that the small effect of autistic symptoms on academic achievement was mediated by the levels of vocabulary skills and behavior problems. These mediators might serve as useful targets for educators in designing educational curricula aimed at promoting academic achievement of children with elevated levels of autistic symptoms. Because results of the cohort-based and the propensity score matched sample were diverging, future research might focus on elucidating whether this divergence is due to low statistical power resulting in a false negative finding or whether there is a real difference between a continuum of autistic symptoms and a classificatory diagnosis of clinical ASD. Including control variables in the analysis to account for potential confounding factors such as comorbid conditions and access to services may provide a clearer understanding of the clinical ASD group. Nevertheless, the method used in our study may provide a prototype for future studies that plan to replicate the matching technique for comparing atypical profiles.

In conclusion, the effect size of the association between autistic symptoms and academic achievement was relatively modest, and we did not find such an association when we took clinical ASD cases into account. Our study therefore implies an optimistic message for families with children with clinical ASD and for schools mainstreaming these children.

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Author contribution Data collection was performed by the Generation R team. NS analyzed the data and wrote the manuscript. ML helped with data analysis and assisted with drafting the manuscript. PJ and PP assisted in drafting the manuscript and reviewed data analysis. MI designed the study, helped with data analysis, and reviewed the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets analyzed during the current study are not publicly available due to the terms and conditions participants agree to when they participate in Generation R but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The Medical Ethical Committee of the Erasmus Medical Center Rotterdam approved the study. We obtained written informed consent from all participants and their parents.

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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