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Clinical and Cognitive Characteristics Associated with Mathematics Problem Solving in Adolescents with Autism Spectrum Disorder

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Abstract

Mathematics achievement in autism spectrum disorder (ASD) has been understudied. However, the ability to solve applied math problems is associated with academic achievement, everyday problem-solving abilities, and vocational outcomes. The paucity of research on math achievement in ASD may be partly explained by the widely-held belief that most individuals with ASD are mathematically gifted, despite emerging evidence to the contrary. The purpose of the study was twofold: to assess the relative proportions of youth with ASD who demonstrate giftedness versus disability on applied math problems, and to examine which cognitive (i.e., perceptual reasoning, verbal ability, working memory) and clinical (i.e., test anxiety) characteristics best predict achievement on applied math problems in ASD relative to typically developing peers. Twenty-seven high-functioning adolescents with ASD and 27 age- and Full Scale IQ-matched typically developing controls were assessed on standardized measures of math problem solving, perceptual reasoning, verbal ability, and test anxiety. Results indicated that 22% of the ASD sample evidenced a mathematics learning disability, while only 4% exhibited mathematical giftedness. The parsimonious linear regression model revealed that the strongest predictor of math problem solving was perceptual reasoning, followed by verbal ability and test anxiety, then diagnosis of ASD. These results inform our theories of math ability in ASD and highlight possible targets of intervention for students with ASD struggling with mathematics.

Keywords

adolescents; mathematics problem solving; anxiety; working memory; perceptual reasoning

Introduction

Half a million children with Autism Spectrum Disorder (ASD) are projected to enter adulthood in the next decade, based on CDC prevalence rates [CDC, 2014]. Research

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suggests that adult outcomes for these individuals are likely to be poor [Howlin, Goode, Hutton, & Rutter, 2004; Roux et al., 2013; Shattuck et al., 2012; Taylor & Mailick, 2014; Taylor & Seltzer, 2010]. Academic achievement in childhood is closely associated with adult educational attainment and vocational success in the typically developing population [Fourqurean, Meisgeier, Swank, & Williams, 1991; Halpern, Yovanoff, Doren, & Benz, 1995;Heal & Rusch, 1994, 1995]. Thus, investigating academic achievement in youth with ASD may shed light on how to help them navigate higher education and transition to the work force. In the present study, we focus on a cornerstone of academic achievement, arithmetic problem solving, which provides a critical foundation for many vocations.

Arithmetic problem solving is understudied in ASD, and there is a wide disparity in perceptions of mathematics abilities in this population. The dominant view is that individuals with ASD are mathematically gifted and tend to pursue majors in science, technology, engineering, and mathematics (STEM). This view has been reinforced by the prevailing theory that individuals with ASD have intact or even superior systemizing, which enables them to excel in a field like mathematics that depends upon systematic, rule-bound procedures and logic [Baron-Cohen, 2002]. This theory has been primarily supported by anecdotal case studies [Gonzalez-Garrido et al., 2002; McMullen, 2000; Thioux, Stark, Klaiman, & Schultz, 2006; Ward & Alar, 2000], as well as the observation that ASD occurs more often in families with parents in the fields of mathematics, engineering, and physics [Baron-Cohen, 1998; Baron-Cohen, Wheel-wright, Skinner, Martin, & Clubley, 2001]. Furthermore, 34% of young adults with ASD enrolled in college reported having a STEM major [Wei, Yu, Shattuck, McCracken, & Blackorby, 2013], which is higher than in the general population [Chen & Weko, 2009] and other disability categories [Wei et al., 2013]. One empirical study [Iuculano et al., 2014] has found above average performance on basic calculation skills but average performance on mathematical reasoning in a group of children with ASD with no intellectual impairment (i.e., high functioning).

A more complex picture has begun to emerge from recent studies regarding the link between mathematical ability and ASD. Most studies of ASD using standardized academic achievement instruments have examined performance on a calculation subtest and found low-average to average achievement in children and adults with ASD [Estes, Rivera, Bryan, Cali, & Dawson, 2011; Goldstein, Beers, Siegel, & Minshew, 2001;Griswold, Barnhill, Myles, Hagiwara, & Simpson, 2002;Jones et al., 2009;Mayes & Calhoun, 2003a, 2003b, 2006, 2008;Szatmari, Tuff, Finlayson, & Bartolucci, 1990]. Jones et al. [2009] examined a subtest of mathematical reasoning and found low-average performance in math word problems for high functioning children with ASD. Further, a nationally representative sample of school-aged students with disabilities revealed that math growth rates for students with autism were significantly slower than those for students with learning disabilities [Wei, Lenz, & Blackorby, 2012]. Overall, these data are inconsistent with the view of pervasive mathematical giftedness in ASD.

Some studies have examined the relative proportion of school-aged students with ASD who demonstrated performance indicative of a mathematics learning disability. The Individuals with Disabilities Education Act [U.S. Department of Education, 1999] defines a learning disability as “a severe discrepancy between achievement and intellectual ability.” Notably, research reveals that 17–40% of high functioning children with ASD had significantly lower mathematics achievement than would be predicted by their IQ [Estes et al., 2011; Mayes & Calhoun, 2003b, 2006, 2008]. These findings suggest that the prevalence of mathematics learning disability in those with high functioning ASD is substantially greater than the 5–7% found in the general population [Shalev, 2007]. Conversely, research indicates that only 13% of higher functioning students with ASD showed mathematical giftedness, as indicated by higher math achievement than would be predicted by their full-scale IQs [Estes et al., 2011]. Jones et al. [2009] examined a sample of adolescents with ASD who represented a broad range of full scale IQs (50–119). For this sample, they found discrepantly poor achievement in 6% for numerical operations and 15% for mathematics reasoning, suggesting that students with ASD may have more difficulty with mathematics reasoning. A recent meta-analysis [Chiang & Lin, 2007] of eight studies suggests that the full range of mathematical ability is represented in the ASD population, with a subset of children with ASD displaying significant difficulty in learning mathematics.

A next critical step in ASD research is to examine factors that may be associated with mathematical achievement in ASD to reveal targets of intervention for those struggling in mathematics. As outlined below, research on typically developing children highlights the importance of *perceptual reasoning* [e.g., Floyd, Evans, & McGrew, 2003;Taub, Keith, Floyd, & McGrew, 2008], *verbal ability* [e.g., Desoete & Roeyers, 2005;Swanson et al., 2004], *working memory* [Swanson, Cooney, & Brock, 1993], and *math anxiety* [Ashcraft & Kirk, 2001; Wu, Willcutt, Escovar, & Menon, 2014] in understanding differences in math achievement. Currently, there is a dearth of research on how these cognitive and clinical characteristics relate to mathematics achievement in ASD.

Perceptual Reasoning

Success in higher mathematics requires perceptual reasoning. Perceptual reasoning consists of nonverbal concept formation, visual perception and information processing, and fluid reasoning skills, which enable one to perceive relationships independent of previous specific practice with them, to think and reason abstractly about such relationships, and to devise strategies for solving problems [e.g., Cattell, 1963, 1971]. Perceptual reasoning is a unique predictor of math achievement in the typically developing population [Floyd et al., 2003; McGrew & Hessler, 1995; Taub et al., 2008]. The same has been found for higher functioning students with ASD. In a study of the four domains of intelligence assessed using the Wechsler Intelligence Scale for Children IV (WISC-IV), the Perceptual Reasoning Index was the strongest predictor of math achievement [Mayes & Calhoun, 2008].

Verbal Ability

Verbal ability may also be critical to solving applied math problems that require reading or oral comprehension and the derivation of the arithmetic equation from this text or speech. Within the typically developing population, research indicates that language factors play a unique role in predicting achievement on applied math problems [Desoete & Roeyers, 2005;Fuchs et al., 2006;Swanson et al., 2004]. To our knowledge, however, no previous study has examined verbal abilities in relation to applied math problems in the ASD population. Along similar lines, Alderson-Day [2014] found evidence of early atypical language development in ASD relating to use of inefficient strategies on verbalproblem solving tasks.

Working memory

Working memory (WM) has been conceptualized as consisting of a central executive, auditory rehearsal loop, and visuo-spatial sketchpad [Baddeley, 1992;Baddeley, Logie, Bressi, Sala, & Spinnler, 1986], where the central executive is involved in controlling encoding and retrieval strategies, attention switching during manipulation of material held in the verbal and visual-spatial systems, and the suppression of irrelevant information [e.g., Miyake et al., 2000]. WM has been hypothesized to be involved in math problem solving because it requires the ability to hold and manipulate numbers and mathematical relations in temporary storage [Mayer & Hegarty, 1996; Swanson, Cooney, & Brock, 1993], and to ignore irrelevant information. Prior studies on typical development have shown that a substantial proportion of the variance related to solution accuracy in word problems is related to WM [e.g., Kail, 2007; LeBlanc & Weber-Russell, 1996; Lee, Ng, & Ng, 2009]. Longitudinal investigations have shown that improvement in WM uniquely predicts typically developing children's math problem solving, even after controlling for the contribution of fluid reasoning, reading, and calculation skills [Swanson, 2011; Swanson, Jerman, & Zheng, 2008]. However, counter to these findings, a study of typically developing adolescents revealed that visual-spatial WM was not a unique predictor of math achievement in computation or applied math problems after accounting for fluid reasoning [Kyttälä & Lehto, 2008], suggesting that future studies which examine the unique and shared contributions of fluid reasoning and working memory to math achievement are warranted. Regarding higher functioning children with ASD, Mayes and Calhoun [2008] found the WISC-IV Full-scale IQ was a better predictor of math achievement than the WISC-IV General Ability Index. The Full-Scale IQ Index, unlike the General Ability Index, includes a measure of WM. Mayes and Calhoun [2008] argued that WM may in part be accounting for the stronger predictive power of Full-Scale IQ Index in math achievement. Research directly examining whether working memory uniquely predicts math achievement in students with ASD is needed to better understand possible math intervention targets.

Anxiety

A final factor that has been associated with mathematics achievement is anxiety [Ashcraft & Kirk, 2001; Owens, Stevenson, Hadwin, & Norgate, 2012]. The Processing Efficiency Theory [Eysenck & Calvo, 1992] proposes that while performing a task, intrusive thoughts and worry associated with high anxiety compete for the limited processing resources of working memory necessary to complete the task. This ultimately results in reduced processing efficiency and leads to slowing of performance and/or to decreased accuracy on the task. Ashcraft and Kirk [2001] have extended this theory to domain-specific anxiety, arguing that math anxiety interrupts working memory processing during math-related tasks, such that there is a negative association between math anxiety and performance [Ashcraft & Kirk, 2001; Wu et al., 2014]. These authors also found that performance on a numerical operations task dropped markedly for a high math-anxiety group compared to a low math-anxiety group specifically when participants concurrently performed a task placing greater demands on working memory [Ashcraft & Kirk, 2001]. Research also indicates that math anxiety is significantly higher in children with math learning disability and/or low achievement compared to those without these problems [Wu et al., 2014]. To our knowledge, the relationship between math anxiety and math problem solving in ASD has not yet been investigated. However, individuals with ASD are at a heightened risk for developing anxiety, including test anxiety [Bellini, 2004;Ghaziuddin, Weidmer-Mikhail, & Ghaziuddin, et al. 1998;Gillott, Furniss, & Walter, 2001;Simonoff et al. 2008;White, Oswald, Ollendick, & Scahill, 2009], suggesting that math anxiety or test anxiety may serve as robust predictors of math achievement and math disability in ASD.

Hypotheses

The current study attempts to shed light on whether individuals with ASD exhibit mathematical giftedness or disability by examining math problem solving performance and its predictors in a group of high functioning adolescents. Our first hypothesis was that a significantly greater proportion of students with ASD would exhibit performance on a math problem solving measure that was indicative of mathematics learning disability versus superior mathematical ability. Second, consistent with the literature review above, we expected that perceptual reasoning, verbal ability, working memory and test anxiety would all uniquely predict math achievement in ASD. Here, we anticipated that perceptual reasoning would be the strongest predictor and that working memory might not serve as a unique predictor when perceptual reasoning was accounted for in the regression model as suggested previously [Kyttälä & Lehto, 2008]. Due to the early stage of research about math problem solving abilities in ASD, we did not make specific predictions about whether the factors under study would differentially account for math achievement (i.e., show interactions with diagnosis) in individuals with ASD compared to those with typical development.

Methods

Participants

Participants consisted of 27 adolescents with ASD and 27 typically developing adolescents. Consistent with the recent CDC prevalence rates (2014) that ASD is almost 5 times more common among boys than girls, our study consisted of 21 males and 6 females in each group. They were recruited from the community through the University of California (UC) Davis MIND Institute's Subject Tracking System database, the MIND Institute's Facebook page, and fliers posted at local public middle and high schools. In both groups, participants ranged from 6th to 12th grade with a mean of 9th grade; participants' grade levels were generally consistent with their ages. All participants had a full-scale IQ > 80 on the Wechsler Abbreviated Scales of Intelligence. The groups were matched on full-scale IQ and nonverbal IQ, with only trend-level differences in verbal IQ (Table 1). For the participants with ASD, the presence of an autism spectrum disorder was confirmed through the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2), which was administered by a clinician experienced in working with adolescents with autism and meeting criteria for research reliability. Of the participants with ASD, 16 completed ADOS-2 Module 3 (mean 11.6, range 8–17) and 11 completed ADOS-2 Module 4 (mean 8.7, range 7–12). All members of the ASD group also met two out of three additional confirmatory criteria: (1) Social

Communication Questionnaire Total score ≥15, (2) Community diagnosis, and (3) DSM-5 autism diagnostic checklist interview conducted by an assessor with a parent. Twenty-four of the 27 ASD group members (89%) met all three confirmatory criteria above and beyond the ADOS-2. Six (22%) members of the ASD group, whereas none in the TYP group, had scores on the revised Conners' Parent Rating Scale (CPRS-R) indicative of attention-deficit/hyperactivity disorder (ADHD) (Global Total scores ≥70). Regarding test anxiety, six (22%) members of the ASD group and three (11%) members of the TYP group were in the at-risk range, and only one (4%) member of the ASD group was in the clinically significant range on the test anxiety content scale of the BASC-2 Self Report of Personality, Adolescent Form [Reynolds & Kamphaus, 2004]. Two ASD group members were taking stimulant medications, but both completed a 48-hr wash-out period before being assessed; two additional ASD participants were taking antidepressant medications. Exclusion criteria for participants in the ASD group included diagnoses of autism with known genetic etiologies and current diagnoses of psychosis. The ADOS-2 was not administered to typically developing participants to detect autism; however, no typically developing participant had a Social Communication Questionnaire Total score ≥15, the screening threshold for autism. Only 15% of the ASD group and 30% of the typically developing control group identified as Hispanic or Latino. In terms of ethnicity, the ASD group was less diverse than the control group: 74% White (vs. 56% of controls), 19% identified with more than one race (vs. 15% of controls), with one Asian participant (vs. 15% of controls), with no participants identifying as Black (vs. 7% of controls) or Pacific Islander (vs. 4% of controls).

After receiving a complete description of the study, participants gave written consent and participants' parents gave written consent. Qualification measures were administered first to ensure eligibility. All measures were administered by a qualified assessor sitting across a table from the participant. Data were collected as part of a larger behavioral and neuroimaging study involving many cognitive measures and questionnaires that were administered in a variety of pseudo-random orders. All aspects of this study were conducted in accordance with a protocol approved by the UC Davis Institutional Review Board.

Measures

ASD Diagnostic Measures

Autism Diagnostic Observation Schedule, Second Edition (ADOS-2) [Lord et al., 2012]. The ADOS-2 is a semi-structured interactive session and interview protocol that provides opportunities for the child to display a number of social and communicative behaviors.

Social Communication Questionnaire, Lifetime Version (SCQ) [Rutter, Bailey, & Lord, 2003]. The SCQ is a parent-report questionnaire with 40 yes-or-no questions about the child's social and communicative behaviors over the child's lifetime. It is used to screen for autism spectrum disorders, with a total score ≥15 indicating the presence of an autism spectrum disorder.

Predictor Variables

IQ measure.—Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II) [Wechsler & Hsiao-Pin, 2011]. The WASI-II is a valid, brief measure of full-scale IQ. The Nonverbal IQ index (Perceptual Reasoning Index; PRI) was used as the measure of perceptual reasoning; the Verbal IQ index (Verbal Comprehension Index; VCI) was used as the measure of verbal ability.

Working memory measure.—Wide Range Assessment of Memory and Learning, Second Edition (WRAML2) [Sheslow & Adams, 2003]. Verbal Working Memory and Symbolic Working Memory subtests were administered to calculate a Working Memory Index score. The Verbal Working Memory subtest requires the participant to recall and manipulate words, while the Symbolic Working Memory subtest requires that they recall and manipulate letters and numbers.

Test anxiety measure.—Behavioral Assessment System for Children, Second Edition: Self Report of Personality, Adolescent Form (BASC-2: SRP-A) [Reynolds & Kamphaus, 2004]. The BASC-2 is a self-report questionnaire with 176 questions designed to facilitate the identification of a variety of emotional and behavioral disorders in children. Test Anxiety, one of the BASC-2 content scales, was used.

Criterion Variable

Math problem solving measure.—Wechsler Individual Achievement Test, Third Edition (WIAT-III) [Wechsler, 2010]. The Math Problem Solving (MPS) subtest of the WIAT-III was administered and used as the criterion in the linear regression models. Completion of the MPS subtest involves solving untimed math problems, which are developmentally graded to relate to basic skills, everyday applications (time, money, etc.), geometry, and algebra. The assessor reads aloud instructions to the participant for each problem. In some, a related figure and/or text is shown. The participant is encouraged to use scratch paper and pencil. The Math Problem Solving subtest has strong psychometric properties including a mean reliability coefficient of .91, interscorer agreement of >98%, and test-retest reliability of 0.86. Given that many mathematical skills evaluated by the Math Problem Solving subtest are explicitly taught according to grade level and are not naturally acquired through development, we deemed it more appropriate to use grade-normed rather than age-normed standard scores to evaluate participants' math achievement. To identify the presence of a learning disability, we used a cutoff/criterion method. Specifically, we used a predetermined cutoff on the Math Problem Solving subtest [Dombrowski, Kamphaus, Reynolds, 2004; Fletcher et al, 2002; Siegel, 1999; Stanovich, 1999], such that children with math achievement <7th percentile (~1.5 *SD below* the mean) were classified as having performance indicative of a math disability. As all participants had a Full-Scale IQ > 80, none had any indication of intellectual disability that would preclude a learning disability. To identify mathematically gifted children, we utilized an analogous cutoff of math achievement >93rd percentile (~1.5 *SD above* the mean). There is controversy regarding the definition of learning disabilities [Scanlon, 2013]. Many clinicians continue to use the actual-predicted discrepancy method to identify learning disabilities (Mayes & Calhoun, 2003b, 2004, 2008; Estes et al., 2011). We also applied the actual-predicted discrepancy method [Breaux and Frey, 2010], which in the case of the present sample, identified the same children as having a math disability as did the cut-off/criterion method.

Data Analysis

To evaluate the first hypothesis, Fisher's exact tests were conducted to investigate group differences in the proportion of participants receiving each classification. To examine associations between the potential predictor variables - perceptual reasoning (NVIQ), verbal ability (VIQ), working memory (WM), and test anxiety (ANX), and the criterion variable math problem solving (MPS), we first conducted two-tailed Pearson correlations. All variables that had $P < 0.2$ for unadjusted associations with math problem solving were selected as candidates and subsequently entered as independent variables in a linear regression model of math problem solving This regression model included a dichotomous variable representing diagnosis of ASD to explore the role of diagnosis in aforementioned relationships. Given the early stage of research about math problem solving in ASD, instead of a step-wise hierarchical linear regression, we considered it most principled to use linear regression involving Type II sums of squares which eliminates the effect of predictor order in the model. Terms that did not add significantly to this model were eliminated and the resulting model was a final parsimonious model. Interaction terms between diagnosis and all significant predictors were also added ant tested into this parsimonious model. Because the independent variables were correlated, we also used regression commonality analysis [Mood, 1971; Newton & Spurrell, 1967; Nimon, 2010] to determine how much variance each variable contributed uniquely and how much it shared with every other variable in the regression model. All analyses were implemented using SPSS version 22.0 [IBM Corp., 2013].

Results

As anticipated, a greater proportion of students with ASD exhibited math achievement indicative of a mathematics learning disability (22%) rather than mathematical giftedness (4%; see Table 2). Furthermore, the ASD group consisted of a significantly greater proportion of participants whose math problem solving indicated a math disability than the typically developing group, Fisher's exact test $P = 0.02$. There were no significant group differences in the proportions of participants receiving average or gifted classifications.

Pearson correlations revealed strong associations between all potential predictor variables and math problem solving, both across the full sample and within each group (all $P < 0.11$) (Table 3). As expected, age was not correlated with scores on the age-normed math achievement measure in either group. Thus, perceptual reasoning, verbal ability, working memory, test anxiety, were added to a linear regression model that included diagnosis. After accounting for the effect of the other variables on math problem solving, only working memory failed to add significantly to the model. Table 4 summarizes the results of the linear regression and the regression commonality analyses, including both unstandardized (B) and standardized (β) coefficients. Standardized coefficients put all of the variables on the same scale, and allow us to compare the magnitude of the coefficients to see which variable has more of an effect. The regression commonality analysis made clear that working memory, which was correlated with math problem solving ($P = 0.05$), was not a significant predictor because there was little variance in math problem solving uniquely attributable to working memory (see Table 4;Unique = 0.07), while the variance shared among working memory and other variables was considerable (Common = 0.15). After removing working memory as a predictor, a final parsimonious linear regression model was tested (Table 4). This parsimonious model accounted for a majority of the variance in math problem solving ($R^2_{adj} = 0.54$) and showed that the strongest predictor of math problem solving was perceptual reasoning (nonverbal IQ; $\beta = 0.39$), followed by verbal ability (verbal IQ; $\beta = 0.30$), test anxiety ($\beta = -0.29$), and diagnosis of ASD ($\beta = -0.26$). Even after accounting for these other significant factors, a diagnosis of ASD was associated with a large deficit in math problem solving ($B = -8.30$). All interaction terms between diagnosis and significant predictors were non-significant and so were not retained in the reported models.

Discussion

The current study indicated that rather than being mathematically gifted, 5.5 times as many students with ASD (22%) evidenced a mathematics learning disability as compared to mathematical giftedness (4%). Moreover, consistent with hypotheses, measures of perceptual reasoning, verbal ability, and test anxiety all displayed unique significant associations with math problem solving in children with ASD and typical development.

As predicted, the regression commonality analysis revealed that perceptual reasoning uniquely accounted for the greatest amount of variance in math problem solving (21.6% of the model) relative to all other predictors. Consistent with a previous study on typical development [Fuchs et al., 2006], working memory did not account for unique variance in math problem solving in children with ASD or typical development. Rather, it shared variance with all the predictors, especially in three-way interactions with Group and each of the other variables (i.e., perceptual reasoning, verbal ability, test anxiety). Notably, controlling for cognitive and anxiety variables reduced the group effect on math problem solving. However, even after controlling for these variables, we still found that for every one point increase in math problem solving in the typically developing control group, there was an 8 point decrease in math problem solving in the ASD group, suggesting that having a diagnosis of ASD also contributed to explaining the variance in math problem solving in a unique way. We did not observe any interactions with group that might provide greater insights into this group effect.

Perhaps the most clinically and educationally relevant finding of our study was that in the ASD sample, 22% evidenced a mathematics learning disability whereas only 4% demonstrated mathematical giftedness. In the general population, approximately 7% of children have a mathematics learning disability [Geary, 2011]. Our data suggest that mathematics learning disabilities may be three times higher in the ASD population. However, caution must be exercised in interpretation of these data given our small sample size. Relative to Estes et al. [2011] we had a greater proportion of students with ASD exhibiting a mathematics learning disability and a much smaller percentage exhibiting mathematical giftedness. Two potential reasons for this discrepancy is that we focused on adolescents and applied math problems, whereas Estes et al. [2011] studied younger children's performance on arithmetic computation. Our work raises the possibility that weaknesses in mathematics become more evident as children with ASD move on to higher grades in which they must engage in complex, applied math problems. This hypothesis is consistent with findings from Jones et al[2009] who found that a greater proportion of adolescents with ASD showed weaknesses on applied mathematics problems relative to computation problems.

A second clinical finding was that test anxiety significantly accounted for unique variance in math problem solving across the whole sample. Specifically within the subsample of youth with ASD, the correlation between test anxiety and math problem solving approached significance ($P = 0.109$). Examining math anxiety in particular, rather than only test anxiety, may provide greater insights into the relation between anxiety and math problem solving in ASD. To our knowledge, the present study is the first to examine the relationship between anxiety and math achievement in ASD. Our data provide new insights into the role that test anxiety may have on the ability of students with ASD to achieve in mathematics, and also raise questions about the role of anxiety in other domains of academic functioning. Our findings suggest that treatments for anxiety, especially test anxiety, or math anxiety, may enhance mathematics achievement in students with ASD or typical development who are struggling with mathematics. Cognitive behavioral therapy [CBT; Wood et al. 2009] and mindfulness training [Spek, van Ham, & Nyklíček, 2013], in addition to psychopharmacological agents have been found to be effective treatments for anxiety in ASD and, therefore, future research in these areas may help to compliment educational interventions for students with ASD. Additionally, more fine-grained longitudinal studies are needed that examine relationships between math achievement in ASD during childhood and its association with adult educational attainment, vocational success, and real-life problem solving.

Notably, working memory was highly correlated with the IQ measures and did not serve as a unique predictor of math problem solving, in line with Fuchs et al. [2006] but counter to Swanson et al. [2004, 2008] and Swanson [2011]. Methodically, our study is more similar to Fuchs et al. [2006] because we placed fewer demands on working memory compared to the Swanson studies [2004, 2008, 2011]. According to the standardized instructions for the WIAT math problem solving measure that we used, we provided participants with scratch paper so that they could write notes and solve the problems on paper rather than only in their head. In Fuchs et al. [2006], participants could request that the story problems be reread. Conversely, in the three Swanson studies [2004, 2008, 2011], after being visually presented with the story problem while hearing each story read aloud only once, participants had to calculate the answer in their heads and were not allowed to look back at the story or use scratch paper. Future studies with larger samples that manipulate the demands placed on working memory for applied math problems would allow for experimenters to assess the role of working memory under different conditions and potentially to illuminate mechanisms accounting for group differences in the role of working memory and language in math problem solving. Despite the fact that we examine associations between the most commonly cited predictors of math problem solving, other factors including executive abilities [Swanson, 2011] and social cognitive factors relevant to ASD (e.g., joint attention and theory of mind), may provide further insights into differences in math achievement between ASD and typical development.

The present study indicates that not all individuals with ASD are gifted in mathematics, but rather there is a range of abilities or subtypes represented in this population. Understanding the strategies these different subtypes use to solve math problems may provide insights into potential targets for intervention for the subtype struggling with mathematics. Iuculano et al. [2014] assessed a sample of children with ASD who scored significantly higher on numeral operations than typically developing peers and discovered that the ASD group relied on sophisticated decomposition strategies more often than the control group to solve these math problems. Future research should examine whether the mathematically gifted subtype found in the ASD population disproportionally uses a decomposition strategy or another strategy, and whether this strategy can be trained in those with ASD who struggle in mathematics.

The current study had several limitations that are important to note. First, our sample was relatively small and there was covariance between variables, which limited the power to detect unique effects or potentially significant group interactions. Additionally, the sample lacked ethnic or racial diversity, with the majority of participants being white and not of Hispanic or Latino ethnicity, and we did not have a measure of socioeconomic status. Further, the sample was disproportionally male, according to the male to female ratio of ASD. Minority ethnic status, socio-economic status, and gender are all associated with lower mathematics attainment [Royer & Walles, 2007]. Further, our study consisted of only higher functioning youth with ASD. Therefore, our findings cannot necessarily be generalized to the full spectrum. It is important that future studies in ASD include greater diversity in their samples. Further, the WASI was used as the measure of perceptual reasoning, which is limited to two subtests. Future research should consider using a measure, such as the Wechsler Intelligence Scale for Children [Wechsler, 2014], that is more sensitive to variability in children and has more nonverbal subtests. Lastly, our study was limited in terms of the assessment of anxiety in that we examined only test anxiety and not also math anxiety.

The present study extends prior research on cognitive predictors of math achievement to the ASD population, but the study was limited because it did not explore other robust cognitive predictors of math that have been identified in research on the general population, such as processing speed [Swanson, 2011;Taub et al., 2008] or inattention [Fuchs et al., 2006]. Although processing speed was not assessed in the current study, we used an untimed math measure, which places fewer demands on processing speed relative to a timed math test. Future studies in ASD should examine the influence of processing speed on math calculation and problem-solving measures that are timed and untimed. Another limitation of the study was that we found a bimodal distribution for inattention, with the typically developing control group scoring significantly lower on inattention traits than the ASD group, which is consistent with the high comorbidity rate of ASD and ADHD found in other studies [e.g., Gjevik, Eldevik, Fjæran-Granum, & Sponheim, 2011;Simonoff et al., 2008;Sinzig, Walter, & Doepfner et al., 2009]. However, this bimodal distribution did not allow for us to include inattention in the model. It is possible that inattention may have accounted for some of the performance decrement that was associated with an ASD diagnosis in our study. Therefore, future studies should include larger samples of typically developing children who represent a broader range of inattention traits and/or control groups of children with ADHD who more closely match children with ASD on inattention traits. Similarly, it would be important for future investigations on academic achievement to compare students with ASD to students with learning disabilities.

Conclusions

The results of the present study underscore the heterogeneity of mathematical ability in higher functioning youth with ASD and challenge the prevalent view that most individuals with ASD are mathematical geniuses. These findings also highlight that it is critical to raise awareness within the scientific field, schools, and general autism community regarding the need to identify and provide interventions for students with ASD who are struggling with mathematics. Not receiving interventions to improve math achievement may have negative long-term effects on students with ASD, as prior research in typical and clinical populations have found that mathematics achievement relates to higher education attainment and job status [Fourqurean et al., 1991; Halpern et al., 1995;Heal & Rusch, 1994, 1995]. Due to the large influx of youth with ASD who will be entering adulthood over the next decade, a greater understanding of the factors that hinder and enhance math ability in ASD is urgently needed as it may help improve adult out-comes for individuals with ASD. Our data point to anxiety as a potential target for intervention to enhance mathematics achievement.

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Table 1.

Participant Characteristics

	ASD (n = 27)		TYP (n = 27)		
Characteristic	**Mean (*SD*)**	**Range**	**Mean (*SD*)**	**Range**	***P*-value[1]**
Age in years IQ	14.88 (1.68)	12.00–17.83	14.73 (1.92)	12.08–17.67	0.75
Verbal IQ	99.48 (12.25)	77–128	105.11 (9.28)	89–122	0.06
Nonverbal IQ	103.19 (12.88)	81–123	103.59 (10.95)	74–122	0.90
Full-Scale IQ	100.89 (11.10)	82–130	104.78 (8.61)	89–125	0.16
Math Achievement	93.67 (16.52)	60–131	106.78 (13.10)	80–134	0.002
Working Memory	98.78 (9.34)	81–116	107.48 (11.50)	86–128	0.004
Test Anxiety	53.00 (9.01)	35–70	49.00 (7.70)	35–64	0.09

From two-sample t-tests.

Note. ASD = Autism Spectrum Disorder. TYP = Typically developing.

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Table 2.

Classification of Groups by Math Achievement

Classification	ASD (*n* = 27) *n* (%)	TYP (*n* = 27) *n* (%)	Fisher's Exact Test *P*-value
Disability	6 (22%)	0 (0%)	.02
Average	20 (74%)	24 (89%)	.29
Gifted	1 (4%)	3 (11%)	.61

Note. ASD, autism spectrum disorder;TYP, typically developing. Disability defined as Math Achievement < 7th percentile. Gifted defined as Math Achievement > 93rd percentile.

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Table 3.

Pearson Correlations

	Verbal IQ			Nonverbal IQ			Working Memory			Test Anxiety		
	ASD	**TYP**	**ALL**	**ASD**	**TYP**	**ALL**	**ASD**	**TYP**	**ALL**	**ASD**	**TYP**	**ALL**
NVIQ	0.18	0.09	0.15									
WM	0.50**	0.37†	0.48***	0.32	0.19	0.23†						
ANX	0.09	0.03	0.00	−0.22	−0.47*	−0.32*	−0.04	− 0.38†	−0.28*			
MPS	0.36†	0.36†	0.42**	0.54**	0.62***	0.53***	0.36†	0.38†	0.46***	−0.32	−0.58**	−0.47***

Note. ASD, autism spectrum disorder ($n = 27$); TYP, typically developing ($n = 27$); ALL, ASD and TYP combined ($n = 54$); VIQ, Verbal IQ; NVIQ, Nonverbal IQ; MPS, Math Problem Solving.

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

† $0.05 \leq P < 0.10$.

Table 4.

Results of the Linear Regression Analysis

		Linear Regression Analysis					Regression Commonality Analysis			
Model	**Predictor**	R^2	R^2_{adj}	B	β	P	**Unique**	**Common**	**Total**	**% of R^2**
Initial		0.58	0.53							
	Diagnosis			−7.73	−0.24	0.03	0.05	0.12	0.17	29.07
	Verbal IQ			0.39	0.27	0.02	0.05	0.12	0.18	30.76
	Nonverbal IQ			0.52	0.38	0.00	0.12	0.16	0.28	48.76
	Working Memory			0.10	0.07	0.54	0.00	0.21	0.21	36.97
	Test Anxiety			−0.51	−0.27	0.01	0.06	0.16	0.22	38.50
Parsimonious		0.57	0.54							
	Diagnosis			−8.30	−0.26	0.01	0.06	0.11	0.17	29.24
	Verbal IQ			0.43	0.30	0.00	0.08	0.10	0.18	30.94
	Nonverbal IQ			0.53	0.39	0.00	0.13	0.15	0.28	49.04
	Test Anxiety			−0.54	−0.29	0.01	0.07	0.15	0.22	38.72

Note. Criterion is Math Achievement. B, estimated coefficient; β estimated standardized coefficient; Unique, predictor's unique effect. Common, Sum of predictor's common effects. Total = Unique + Common. % of R^2 = Total/R^2.