

NUMERICAL COMPETENCIES IN AUTISM

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**Early Numerical Competencies in 4- and 5-Year-Old Children with Autism Spectrum
Disorder**

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Abstract

Studies comparing mathematical abilities of children with autism spectrum disorder (ASD) and typically developing children are hitherto scarce, inconclusive, and mainly focusing on elementary school children or adolescents. The current study wants to gain insight into the foundation of mathematics by looking at preschool performances. Five early numerical competencies known to be important for mathematical development were examined: verbal subitizing, counting, magnitude comparison, estimation, and arithmetic operations. These competencies were studied in 20 high-functioning children with ASD and 20 age-matched control children aged 4 and 5 years. Our data revealed similar early number processing in children with and without ASD at preschool age, meaning that both groups did not differ on the foundation of mathematics development. Given the pervasiveness and the family impact of the condition of ASD, this is an important positive message for parents and preschool teachers. Implications and several directions for future research are proposed.

Keywords: early numerical competencies, preschool, autism spectrum disorder

The interest in the academic functioning of children with autism spectrum disorder (ASD) has grown rapidly over the past few years. More and more children with ASD follow the regular educational program in general education settings, with or without additional guidance (Whitby & Mancil, 2009). Yet, given the high heterogeneity in autism spectrum disorders, there is a wide variation in the level of functioning (Georgiades, Szatmari, & Boyle, 2013). As such, at least some children experience problems with their academic trajectory (Lanou, Hough, & Powell, 2012) and teachers are challenged to provide a comprehensive way of explaining subject matters (Kagohara, Sigafos, Achmadi, O'Reilly, & Lancioni, 2012).

Mathematics seems to be one of the stumbling blocks for quite a large number of children, as there is a growing demand from clinical practice for adapted teaching methods on this subject (Department for Education and Skills, 2001; van Luit, Caspers, & Karelse, 2006). Three major cognitive theories dominate the psychological research into autism spectrum disorders (Rajendran & Mitchell, 2007): the theory of mind (Baron-Cohen, Leslie, & Frith, 1985), the theory of executive dysfunction (Ozonoff, Pennington, & Rogers, 1991), and the weak central coherence (WCC) theory (Frith, 1989). Previous research already demonstrated that the autism-specific cognitive profile may impact upon academic performance (Fleury et al., 2014; Jones, 2006; Pellicano, Maybery, Durkin, & Maley, 2006). Whether these cognitive theories can also be applied to explain in particular the mathematical profiles of children with ASD remains questionable, as research connecting these two topics hardly exists. One could for example assume an impact of theory of mind abilities on mathematical exercises involving perspective-taking, such as mathematical word problems. Moreover, since one of the aetiological cognitive factors supposedly contributing to mathematical learning disorders (MLD) constitutes of deficits in executive functions (e.g., Andersson & Ostergren, 2012), one might also expect to observe mathematical problems in children with ASD. Finally, the WCC theory can be linked to serial counting strategies (Gagnon, Mottron, Bherer, & Joanne, 2004;

Jarrold & Russell, 1997), and to a discrepancy between preserved procedural and impaired conceptual skills in children with ASD (Goldstein, Minshew, & Siegel, 1994; Minshew, Goldstein, Taylor, & Siegel, 1994, Noens, & van Berckelaer-Onnes, 2005). As such, autism-specific characteristics might impact, both negatively or positively, on mathematical functioning.

According to Mayes and Calhoun (2006), 23% of the children with autism have a MLD. Reitzel and Szatmari (2003) stated that 73% of the children with high-functioning autism (HFA) and 35% of the children with Asperger syndrome (AS) have a general MLD, defined as a standard score < 80 on a mathematical achievement test. Moreover, 12% of the HFA-group and 46% of the AS-group has a specific MLD, defined as an IQ > 80 and minimum 15 points discrepancy with a math achievement test. These percentages are substantially higher than the prevalence estimates of MLD in the general school-aged population, which range from 3 to 14% (American Psychiatric Association [APA], 2013; Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005).

To date, studies comparing directly the mathematical abilities of children with ASD and typically developing (TD) children are scarce. The review of Chiang and Lin (2007) demonstrated average mathematical abilities in the majority of individuals with AS or HFA (aged 3 to 51 years) compared to the normed population. This was in line with previously reported average to good mathematical abilities of individuals with AS by Church, Alisanski, and Amanullah (2000). More recently, Iuculano et al. (2014) demonstrated even better numerical problem solving abilities in elementary school children with HFA than in TD peers. None of these studies, however, provides a comprehensive overview of the mathematical abilities of children with ASD or focus on the important developmental period of preschool age. Yet, several studies already demonstrated the importance of early numerical competencies as precursors for mathematical achievement later on, encouraged by the

objective to prevent children from falling further behind by means of addressing early precursors as key components in remediation programs (DiPema, Lei, & Reid, 2007; Gersten et al., 2012; Jordan, Kaplan, Ramineni, & Locuniak, 2009).

Since practitioners often report mathematical difficulties in children with ASD from elementary school onwards, it can be important to investigate early or preparatory competencies at a younger age, allowing us to get insight into the possible precursors of the reported problems. If differences occur already at preschool level, this may suggest pre-existing difficulties with number processing leading to problems with mathematics later on.

Early Numerical Competencies

Children enter elementary school with varying levels of early number competencies (Jordan & Levine, 2009; Powell & Fuchs, 2012). Although it is clear that these early numerical competencies can be differentiated from the more complex mathematical abilities acquired through formal schooling, there is no consensus on the precise definition or even the term used to describe this set of abilities (Kroesbergen, Van Luit, & Aunio, 2012). The current study included five early numerical competencies described in the work of Jordan and Levine (2009). All five competencies have proven to be important predictors of later mathematics achievement (Jordan & Levine, 2009).

Verbal subitizing. Subitizing is the rapid (40-100 ms/item) and accurate assessment of small quantities of up to three (or four) items (Kaufman, Lord, Reese, & Volkmann, 1949). Whereas children use counting to determine the exact numerosity of a large set of items, subitizing is considered to be a more automatic process for the precise representation of small numerosities (Dehaene, 1992; Nan, Knosche, & Luo, 2006). Various studies have shown a relationship between subitizing abilities and later mathematics achievement (Desoete & Grégoire, 2006; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009;

Reeve, Reynolds, Humberstone, & Butterworth, 2012). Moreover, subitizing is sometimes investigated as a core deficit in children with MLD (Fischer, Gebhardt, & Hartnegg, 2008; Schleifer & Landerl, 2011). Several studies suggested that children with ASD, due to a weaker central coherence (Frith & Happe, 1994), use a serial counting strategy rather than subitizing to enumerate small quantities (Gagnon et al., 2004; Jarrold & Russell, 1997). Nevertheless, no significant differences in reaction times or accuracy have been reported when comparing 15-year-old adolescents with ASD with TD peers (Gagnon et al., 2004) and children with and without ASD with a verbal mental age of 6.92 years (Jarrold & Russell, 1997). Regarding larger numerosities, it has been reported that some individuals with ASD show a process similar to that of subitizing to estimate these quantities (Snyder, Bahramali, Hawker, & Mitchell, 2006). However, this ability is considered as a savant skill that is only present in a very limited number of people with ASD (Snyder et al., 2006).

Counting. Counting knowledge can be subdivided into procedural (the ability to perform a counting task) and conceptual (the understanding of why a procedure works or is legitimate) aspects (LeFevre et al., 2006). Although closely related to each other, these two aspects seem to be mastered separately (Dowker, 2005). Previous studies indicated that children master the essential counting principles at age four to five, but some children acquire these abilities only later on (Le Corre & Carey, 2007; Stock, Desoete, & Roeyers, 2009). Since the 1980s, a large body of evidence has proven the central influence of counting on the development of adequate mathematical abilities and its supporting role in early mathematical strategies (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Fuson, 1988; Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990). Moreover, children with a MLD showed deficient counting abilities, indicating the importance of adequate and flexible counting knowledge (Dowker, 2005; Geary, Bowthomas, & Yao, 1992; LeFevre et al., 2006). As yet, there are no studies available on the counting abilities of individuals with ASD.

Magnitude comparison. Magnitude comparison is the ability to discriminate two quantities in order to point out the largest of both (Gersten et al., 2012), on the condition that the distance or ratio between the quantities is large enough (Halberda & Feigenson, 2008). The precision with which this can be done increases with age until young adulthood (Halberda & Feigenson, 2008). Several studies demonstrated a relationship between the distance effect on a magnitude comparison task and later mathematics achievement (De Smedt, Verschaffel, & Ghesquiere, 2009; Holloway & Ansari, 2009) and the weaker performance of children with a MLD on such tasks (Landerl, Bevan, & Butterworth, 2004; Mazzocco, Feigenson, & Halberda, 2011). To date, there is some evidence that children with ASD might show superior magnitude comparison abilities (Soulieres et al., 2010).

Estimation. Estimation, often investigated with a number line task, is an important skill both in classroom and everyday life (Siegler & Opfer, 2003). Research indicates that the gain in precision of number line judgments is characterized by a developmental transition from a logarithmic representation to a more formally appropriate linear one, suggesting a changing representation with increasing formal schooling (Siegler & Booth, 2004; Siegler & Opfer, 2003). The importance of this evolution is demonstrated in studies indicating that the linearity of judgments is positively correlated with math achievement scores (Ashcraft & Moore, 2012; Siegler & Booth, 2004). Moreover, compared to TD children, children with MLD are less accurate in their judgments and rely more on a logarithmic representation when dealing with this task (e.g., Geary, Hoard, Nugent, & Byrd-Craven, 2008). As yet, no studies have examined number line estimation in children with ASD.

Arithmetic operations. Arithmetic operations find themselves on the border between early numerical competencies and the more advanced mathematical knowledge acquired through formal teaching (Purpura & Lonigan, 2013). A first step to learn these simple addition and subtraction number combinations is often the use of manipulatives, followed by

finger counting and eventually the use of reasoning strategies and memory-based retrieval (Groen & Resnick, 1977; Powell & Fuchs, 2012). Arithmetic operations can be measured through simple addition and subtraction exercises either with or without manipulatives, two-set addition, (de)composition of sets, and number combinations (Purpura & Lonigan, 2013). Several studies demonstrated a relationship between arithmetic operations and later math achievement (Jordan, Glutting, & Ramineni, 2010; Jordan et al., 2009). Moreover, children with MLD perform worse on mathematical story problems than TD peers (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan & Hanich, 2000). To date, there are no studies investigating arithmetic operations in children with ASD.

Objectives and Research Questions

Practitioners often report mathematical difficulties in children with ASD (Department for Education and Skills, 2001; van Luit et al., 2006). Moreover, as stated above, several ASD-specific information processing characteristics could have an influence on mathematics performance. Hence, further research tackling this issue is warranted.

Whereas previous research often focused on one single aspect of mathematics (e.g., Gagnon et al., 2004) or used a composite math score (e.g., Chiang & Lin, 2007), the current study uses a multi-componential approach and incorporates different subcomponents of early mathematics. In addition, the current study puts a focus on the important developmental period of preschool age. As students who perform poorly on early numerical competencies tend to perform poor on mathematical achievement tests later on, early identification aimed at building interventions might be important (Dowker, 2005; Duncan et al., 2007).

The current study compares five early numerical competencies in TD children and high-functioning children with ASD at preschool age: verbal subitizing, counting, magnitude comparison, estimation, and arithmetic operations. The main goal is to investigate whether

children with ASD differ in mathematics – encounter problems or show strengths – already before formal schooling starts. Moreover, the study wants to identify for which of the early numerical competencies this is the case. Furthermore, the findings of this study are intended to direct future research. If preschool differences can be found, future research should focus on the underlying processes – such as autism-specific information processing characteristics – causing the differences in order to set up tailored interventions to prevent further problems. If no preschool differences can be found, this study may point to problems during formal schooling and provide some indications for the need of an evaluation or adaptation of the currently used teaching materials or methods.

The current study aims to present an exploratory analysis of the early numerical competencies in 4- and 5-year-old children with and without ASD. Given the scarce and inconsistent results from previous studies, no specific hypotheses were postulated.

Method

Participants

Forty children (34 boys, 6 girls) with a mean age of 5.05 years ($SD = 0.32$) participated. In the Flemish part of Belgium, children typically attend preschool when they are aged 2.5 years, and enter elementary school at around age 6. Children usually attend preschool for 3 years. Although preschool education is not compulsory, the vast majority of children do attend preschool. Formal (with defined curriculum) and compulsory education starts in first grade. In the current study, all children had received two years of preschool education at the moment of testing. All children, although recruited from different schools, attended mainstream educational settings or special education specifically focused on high-functioning children with ASD. Within these two settings, the same “developmental goals”

(i.e., a set of basic competencies that need to be acquired at the end of preschool) are set. As such, the children were assumed to receive similar preschool experiences concerning preparatory mathematics.

Children with ASD (17 boys, 3 girls) were recruited through rehabilitation centers, special school services and other specialized agencies for developmental disorders. They had a formal diagnosis made independently by a qualified multidisciplinary team according to established criteria, such as specified in the DSM-IV-TR (APA, 2000). For all children, this diagnosis was confirmed by a score above the ASD cut-off on the Dutch version of the *Social Responsiveness Scale (SRS)* (Roeyers, Thys, Druart, De Schryver, & Schittekatte, 2011). The Dutch version of the *SRS* has a good internal consistency, with a Cronbach's alpha of .94 for boys and .92 for girls (Roeyers et al., 2011). Scores on the *Autism Diagnostic Observation Schedule (ADOS)* (Lord et al., 2000) were available for 9 children with ASD. Children with and without *ADOS*-scores did not differ significantly on the *SRS*, $U = 35.00$, $p = .295$.

TD children (17 boys, 3 girls) were recruited using invitation letters send to different preschool settings. There was no parental concern of developmental problems and all children scored below the ASD cut-off on the *SRS* (Roeyers et al., 2011).

Each participant had a full scale IQ (FSIQ) of 80 or more, measured with the *Wechsler Preschool and Primary Scale of Intelligence – Third edition (WPPSI-III)* (Wechsler, 2002). As such, the study focused on a group of high-functioning children with ASD. Due to the inclusion criteria of the *SRS* and the *WPPSI-III*, 6 children with ASD and 2 TD children were excluded from the study, resulting in 40 participants. Table 1 provides an overview of the sample characteristics.

< Insert Table 1 about here >

All ASD children were selected first and invitation letters for TD children were then sent home. Due to practical concerns, the TD children were not all from the same preschools as the children with ASD. However, the two groups were matched on age, FSIQ, sex ratio, and socio-economic status (*Hollingshead four factor index of social status*; Hollingshead, 1975) on group level.

Materials

Verbal subitizing and magnitude comparison were tested with computerized enumeration and magnitude comparison tasks. In the enumeration task (taking 15 minutes to complete), a display containing one to nine square boxes was centrally presented at fixation until a vocal response was detected. Participants were instructed to say aloud the number of squares on the screen as quickly and accurately as possible. Both accuracy (% correct) and mean reaction times (based on correct trials only) were used as outcome variables. Cronbach's alpha was .88.

In the magnitude comparison task (taking approximately 15 minutes to complete), two displays of black dots on a white background were presented simultaneously on a 17 inch monitor. On top of the two displays, an illustration of a sun and a moon were presented. Participants were instructed to press the sun- or the moon-button corresponding to the largest numerosity on a response box as quickly and accurately as possible. Six different ratios were presented. When dividing the smallest by the largest numerosity, these ratios were: .33, .50, .67, .75, .80, and .83. Different numerosities (e.g., 1 vs. 2, 2 vs. 4 ...) were used to operationalize each ratio (e.g., .50). Both accuracy (% correct) and mean reaction times (based on correct trials only) were used as outcome variables. Cronbach's alpha was .80.

Counting and arithmetic operations were tested with three subtests of the *Test for the Diagnosis of Mathematical Competencies (TEDI-MATH*; Grégoire, Noël, & Van Nieuwenhoven, 2004), a Belgian individual assessment battery constructed to detect mathematical problems from the second year of preschool until the third grade in elementary school. Procedural counting was assessed using accuracy in counting row and counting forward to an upper bound and/or from a lower bound. Conceptual counting was assessed by judging the validity of counting procedures based on the five basic counting principles formulated by Gelman and Gallistel (1978). In order to investigate these principles, children had to judge the counting of both linear and nonlinear patterns of objects, and were asked some questions about the counted amount of objects. Furthermore, they had to construct two numerically equivalent amounts of objects and had to use counting as a problem-solving strategy in a riddle (e.g., ‘Here you can see some snowmen wearing a hat.’ After taking away all the hats and putting them underneath a box, the experimenter asks : ‘How many hats are there covered under this box?’). Finally, arithmetic operations were assessed with a series of six visually supported addition and subtraction exercises. Cronbach’s alpha was .73 for procedural counting, and .85 for conceptual counting and arithmetic operations. The tasks took approximately 15 minutes to complete.

Finally, estimation was tested using a 0-10 number line estimation task. Stimuli were presented as Arabic numerals (e.g., anchors 0 and 10, target number 2); spoken number words (e.g., anchors zero and ten, target number two), and dot patterns (e.g., anchors of zero dots and ten dots, target number two dots). Children were asked to put a single mark on the line to indicate the location of the number. Although the instructions could be rephrased if needed, no feedback was given to participants regarding the accuracy of their marks.

The percentage of absolute error (PAE) was calculated per child as a measure of children's estimation accuracy, following the formula of Siegler and Booth (2004):

$$PAE = \left| \frac{\text{Estimate} - \text{Estimated Quantity}}{\text{Scale of Estimates}} \right| \times 100$$

For example, when a child puts a mark at 6.5 when asked to situate 5 on the number line, the percentage of absolute error is $[(6.5 - 5) / 10] \times 100 = 15\%$. Next to percentages of absolute error, the underlying representation (linear or logarithmic) of the estimates was also investigated. In order to do this on group level, the procedure of Siegler and Opfer (2003) was used. Regression analyses on the group median estimates (plotting median estimates against the actual to be estimated values) were used to compute both linear and logarithmic fits (R^2 values) for the TD children and the children with ASD. The difference between the linear and logarithmic regression models was tested with a paired samples t-test. On individual level, following the procedure of Berteletti, Lucangeli, Piazza, Dehaene, and Zorzi (2010), each child was attributed the best fitting significant model between linear and logarithmic. A child was classified as not having a valid representation when both linear and logarithmic coefficients failed to reach significance or when slopes were negative (indicating an inverse relationship as the one to be expected). Cronbach's alpha was .87 for the total task. The task took approximately 15 minutes to complete.

Figure 1 provides an example of the test items. For more information about the materials we refer to Titeca, Roeyers, Josephy, Ceulemans, and Desoete (2014).

< Insert Figure 1 about here >

Procedure

The study was approved by the ethical commission. Parents received an information letter and signed an informed consent before their participation. Children were assessed individually, but the tests were presented in the same order for all children. It took approximately two hours for participants to complete the test battery. The assessment was spread over two different test sessions. In the first session, children were assessed with the WPPSI-III (Wechsler, 2002) and with the computerized tasks (verbal subitizing and magnitude comparison). During the second session, children were assessed with the TEDI-MATH tasks (counting and arithmetic operations) and the number line task (estimation). All test leaders (graduate students) received training in the assessment and interpretation of the tests.

Results

In order to check whether the sampling distribution of the variables was normally distributed within groups, a Shapiro-Wilk test (for sample sizes lower than 50; Field, 2009) was used. Parametric analyses were conducted, except for the cases in which the assumption for normal distributions was violated ($p < .050$). Table 2 provides an overview of the correlations between all variables. However, only few significant correlations were found between the constructs and after applying a Bonferroni correction ($p < .001$), none of the correlations remained significant.

< Insert Table 2 about here >

Significantly different correlation patterns seem to emerge for TD children and children with ASD for some of the variables (*Fisher r-to-z transformations*, $p < .050$). There was a significantly stronger negative correlation between verbal subitizing (reaction time) and conceptual counting knowledge in ASD children compared to TD peers. In TD children, there

was a stronger negative correlation between verbal subitizing (reaction time and accuracy) and arithmetic operations and between magnitude comparison (reaction time) and the number line estimation errors (PAE) compared to children with ASD.

Verbal Subitizing

Due to technical reasons (recording problems), the results of six TD children and four children with ASD were not recorded. In addition, one child with ASD was excluded, as the child did not understand the task properly and could not complete it. Therefore, analyses were conducted on 14 TD children and 15 children with ASD. Graphical inspection of the accuracy rates revealed very low accuracy scores for larger numerosities (> 5). As such, only numerosities 1 to 5 were included in the reaction time analyses. This range of numerosities was chosen because 5 was the highest numerosity at which reaction time data were present for more than half of the children ($n = 19$). A Friedman ANOVA demonstrated a significant main effect of Numerosity in both groups, $\chi^2(4) = 16.44, p = .002$ in the TD group ($n = 9$) and $\chi^2(4) = 16.96, p = .002$ in the ASD group ($n = 10$), with higher reaction times for increasing numerosities. A Mann-Whitney U test revealed no significant difference in mean reaction time for the range 1-5 between the two groups, $U = 102.00, p = .914$. When focussing specifically on the subitizing range (1-3), there was also no significant difference between the two groups, $U = 84.00, p = .377$.

< Insert Figure 2 about here >

For accuracy, a Friedman ANOVA on all numerosities revealed a significant main effect of Numerosity in both groups, $\chi^2(8) = 79.86, p < .001$ in the TD group ($n = 14$) and $\chi^2(8) = 94.67, p < .001$ in the ASD group ($n = 15$), with lower accuracy rates for increasing numerosities (see Figure 2). No significant differences in total accuracy, $U = 69.50, p = .123$,

or accuracy in the subitizing range (1-3), $U = 68.00$, $p = .112$, were found between the groups.

Counting

An independent samples t-test revealed no significant difference neither in procedural counting knowledge, $t(38) = -0.43$, $p = .673$, nor in conceptual counting knowledge, $t(38) = 0.12$, $p = .903$, between children with ASD and TD children.

Magnitude Comparison

Due to technical reasons (recording problems), the results of six TD children and four children with ASD were not recorded; analyses were conducted on 14 TD children and 16 children with ASD. A repeated measures analysis on mean reaction time with Ratio as within subject factor and Group as between subject factor revealed no significant main effect of Ratio, $F(5, 24) = 1.85$, $p = .140$, or Group, $F(1, 28) = 0.12$, $p = .728$. Moreover, there was no significant Ratio by Group interaction, $F(5, 24) = 0.10$, $p = .990$

< Insert Figure 3 about here >

For accuracy, a repeated measures analysis revealed a significant main effect of Ratio, $F(5, 24) = 16.78$, $p < .001$. However, there was no significant main effect of Group, $F(1, 28) = 0.26$, $p = .614$, and no Ratio by Group interaction, $F(5, 24) = 0.70$, $p = .632$ (see Figure 3).

Estimation

Three TD children and three children with ASD were excluded from the analyses, as they did not understand the task properly (i.e., positioning all estimations in the middle or positioning all estimations at one anchor). A Friedman ANOVA demonstrated no significant differences in percentages of absolute error between the formats using Arabic numerals,

Number words and Dot patterns, $\chi^2(2) = 2.47$, $p = .291$ in the TD group and $\chi^2(2) = 1.41$, $p = .494$ in the ASD group. A Mann-Whitney U test indicated no significant difference between the groups for the total percentage of absolute error, $U = 104.00$, $p = .170$ (see Figure 4).

< Insert Figure 4 about here >

When investigating the shape of the curve, the underlying representation was examined both at group and individual level. The best fitting representational model for the overall number line task was linear for both the TD group, $R^2_{\text{lin}} = .91$, $p < .001$, and the ASD group, $R^2_{\text{lin}} = .96$, $p < .001$. However, this linear fit was not significantly different from the logarithmic model in both the TD group, $R^2_{\text{log}} = .86$, $p < .001$; $t(8) = -1.01$, $p = .342$, and the ASD group, $R^2_{\text{log}} = .90$, $p < .001$; $t(8) = -2.16$, $p = .063$.

At the individual level, no significant differences were found between the allocation to the no valid representation (TD: 23.53%; ASD: 52.94%) – logarithmic representation (TD: 41.18%; ASD: 11.76%) – linear representation (TD: 35.29%; ASD: 35.29%) categories between both groups, *Fisher exact test*, $p = .122$.

Arithmetic Operations

A Mann-Whitney U test revealed no significant difference in the ability to execute arithmetic operations between TD children and children with ASD, $U = 184.50$, $p = .678$.

Discussion

This study aimed at comparing the five early numerical competencies as outlined in the review of Jordan and Levine (2009) between 4- and 5-year-old children with and without ASD, attending second year of preschool. Despite the clinical concerns and the theoretical arguments to assume an influence of some autism-specific information processing

characteristics on mathematical abilities, research on mathematics in children with ASD is rather scarce and is just starting to become a topic of interest. Therefore, the goal of this study was to provide an exploratory analysis of possible differences in mathematical abilities at preschool age – a necessary first step before deciding whether investigating underlying processes is useful.

Overall, the current small sample size study found similar early number processing in children with and without ASD at the age of 4 or 5 years. This finding is consistent with some of the previous studies that targeted mathematical abilities of children with ASD at a later age, and found average mathematical abilities compared to the normed population (Chiang & Lin, 2007; Church et al., 2000; Iuculano et al., 2014). Moreover, no significant correlations were found between ASD symptomatology and early numerical competencies. The fact that we observed a similar foundation of mathematical development in high-functioning children with ASD as in TD children could be an important finding if replicated in larger sample studies. Given the pervasiveness of the condition of ASD on other domains of functioning (Jones, 2006), it could be encouraging to know that no additional concerns should be raised on the early numerical competencies.

Next to these general findings, some results will be discussed and related to previous findings in more detail below. Regarding *verbal subitizing*, our results are in line with previous findings that demonstrated no significant differences in reaction times or accuracy rates in older children (Jarrold & Russell, 1997) or adolescents with ASD (Gagnon et al., 2004). Moreover, we found no indications of a process similar to subitizing for larger numerosities (Snyder et al., 2006) in preschoolers with ASD, as reflected by the increase in reaction time and the large decrease of accuracy for larger numerosities. Our task was specifically designed to assess subitizing (giving the participants not enough time to count all items) and therefore it is clear that our participants (with or without ASD) did not succeed in

subitizing/quickly estimating larger numerosities. For *magnitude comparison*, our results expounded on the case study of Soulieres et al. (2010) and revealed no significant differences between children with ASD and TD children. Given the large behavioural heterogeneity in children with ASD (Georgiades et al., 2013), it remains possible that some children show superior performance on for example magnitude comparison. However, our results revealed that this superior performance does not necessarily hold when examining children with ASD at group level. Despite the fact that the *estimation* task was operationalized in a different way compared to previous studies (three formats instead of Arabic numerals only), the percentages of absolute error (24% for TD children and 28% for children with ASD) were similar to a previous report for the same 0-10 interval at the same age (24% in Berteletti et al., 2010). Although previous research indicated divergent findings depending on the format (symbolic versus non-symbolic) that was used (De Smedt, Noël, Gilmore, & Ansari, 2013), the added value of incorporating different presentation formats could not be demonstrated in the current study.

Strengths and Limitations

Since previous studies on mathematical abilities in children with ASD are scarce and investigate mostly older children or adolescents, the current study provides valuable insights into the important developmental period of preschool age. Early numerical competencies are predictive for later mathematics in TD children (Jordan & Levine, 2009). As such, studying these precursors can also be informative in children with ASD. However, it is recommended that future research adopts a longitudinal approach to confirm these findings and to indicate their predictive value in children with ASD.

In addition, whereas previous research often focused on one single aspect of mathematics (e.g., Gagnon et al., 2004) or used a composite math score (e.g., Chiang & Lin,

2007), the current study used a multi-componential approach and incorporates the different early numerical competencies described by Jordan and Levine (2009). In this way, the study provided the possibility to reflect a differentiated profile of strengths, average scores, or weaknesses if such divergent scores on early numerical competencies would be present. Moreover, the use of a matched control group instead of the normed samples of standardized achievement tests makes a more reliable and direct comparison possible on all competencies.

The results of the current study should however be interpreted with care, as only a small number of children were included in the sample. Obviously, sample size is not a problem for significant differences, but when analyses have insufficient power and are not significant, a risk of type 2- or β -mistakes cannot be excluded. The number line estimation data, for example, showed a somewhat higher accuracy for TD children compared to children with ASD (see Figure 4) and quite large differences in allocations to representation categories; differences which might turn significant in larger samples. Additional research with a larger group of participants is therefore definitely indicated. In addition, the TD preschoolers did not all come from the same preschools as the children with ASD, so there might not be a perfect matching. Moreover, the current study only included high-functioning children with ASD, so additional studies on children with ASD with average or below average intelligence are recommended.

Next, given the typical heterogeneity in academic profiles of children with ASD (e.g., Estes, Rivera, Bryan, Cali, & Dawson, 2011; Georgiades et al., 2013), it might also be interesting to look for possible subgroups of children. Looking at average scores may mask subgroups of individuals with remarkable poor or excellent skills (Jones et al., 2009). As such, future research with larger groups of children could consider to conduct cluster analyses to identify possible subgroups.

Finally, it is important to note that although the instruments are previously used in TD populations or children with MLD (e.g., Berteletti et al., 2010; Praet et al., 2013; Stock, Desoete, & Roeyers, 2007), most of the instruments have never been used in an ASD group before. In addition, the wide range of test trials of the different early numerical competencies can be considered as a limitation which may have influenced the results.

Implications

The current small sample size study indicated no significant differences in early numerical competencies between children with ASD and TD children at the ages of 4 and 5 years. Given the pervasiveness and the family impact of the condition of ASD (Karst & Van Hecke, 2012), this message can be considered to be valuable to communicate to parents and teachers. Acknowledging strengths and abilities is important, not only to compensate for weaknesses, but also for increasing self-esteem and well-being (Jones, 2006). In addition, based on these findings, we could assume that the instructional approaches of early numerical competencies used by teachers should not be adapted specifically for high-functioning children with ASD. Instead, we would recommend to create learning environments and to use teaching materials that raise possibilities for all children, such as conceptualized within the *Universal Design for Learning* (UDL) framework. A UDL framework aims at creating learning environments and adopting teaching materials and practices that allow for participation by all children, regardless of individual learning differences (Hanna, 2005). As such, UDL principles lend themselves to implement inclusionary practices in general educational settings, because it consists of flexible approaches that can be customized and adjusted for individual needs (Hitchcock, Meyer, Rose, & Jackson, 2002). In such a design, all children get enough time with a daily relooping of previously learning material and an

explicit vocabulary building. As such, all children benefit from the adjusted speed and adequate support of numerical competencies.

However, given the small and selective sample of the current study and the concerns on mathematics in elementary school children with ASD formulated by clinicians and practitioners, it is still warranted to follow up the mathematical abilities at later ages, since the transition to formal schooling with its increasing requirements of the curriculum, could have an impact on mathematics performance. Thus, continued or school entry assessment is warranted to see ongoing trajectories to determine if benchmark performance maintains.

Conclusion

The current small data set study indicates no significantly different performance on early numerical competencies in children with ASD and TD children at 4 and 5 years of age. Future research and larger sample size studies as well as continued monitoring during schooling seem indicated to investigate whether or not differences in mathematics performance arise gradually during schooling.

Conflict of interest statement

The authors state no conflict of interest in the current study.

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Figure captions

Figure 1. Summarizing overview of materials to assess early numerical competencies.

Figure 2. Verbal subitizing - Accuracy in function of numerosity.

TD = typically developing children; ASD = children with autism spectrum disorder.

Figure 3. Magnitude comparison - Accuracy in function of ratio.

TD = typically developing children; ASD = children with autism spectrum disorder.

Figure 4. Estimation - Percentages of absolute error in function of format.

TD = typically developing children; ASD = children with autism spectrum disorder.

Table 1

Descriptive characteristics of the sample.

	TD (<i>n</i> = 20)		ASD (<i>n</i> = 20)		
	<i>Mean</i>	(<i>SD</i>)	<i>Mean</i>	(<i>SD</i>)	
Age (in years)	4.98	(0.29)	5.13	(0.33)	$t(38) = -1.57, p = .125$
FSIQ ^a	106.50	(11.61)	105.30	(13.90)	$t(38) = 0.30, p = .769$
VIQ	108.60	(13.76)	104.75	(12.26)	$t(38) = 0.93, p = .356$
PIQ	104.55	(7.98)	106.90	(17.78)	$t(26.35) = -0.54, p = .593$
SES ^b	47.76	(9.66)	45.30	(9.47)	$U = 145.00, p = .214$
SRS (T-score) ^c	46.90	(8.53)	86.25	(23.77)	$U = 19.00, p < .001$

Note. Whenever the sampling distribution of the variables was not normally distributed, non-parametric analyses were conducted. TD = typically developing children; ASD = children with autism spectrum disorder. ^aFull Scale IQ, measured with *Wechsler Preschool and Primary Scale of Intelligence – Third edition*; ^bSocio-economic status, measured with *Hollingshead Index*; ^cT-score on *Social Responsiveness Scale*.

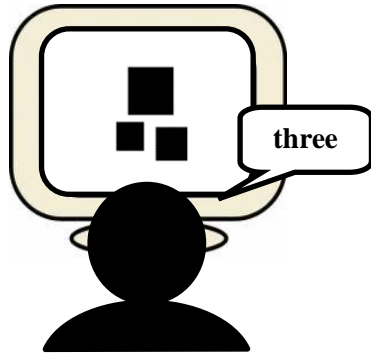
Table 2

Correlations between early numerical competencies, FSIQ and severity of ASD symptomatology.

		Verbal subitizing		Counting		Magnitude comparison		Estimation
		RT (1-3)	Accuracy (1-3)	Procedural	Conceptual	Overall RT	Overall accuracy	Overall PAE
Verbal subitizing	RT (1-3)	TD	-					
	ASD	-						
Accuracy (1-3)	TD	.45	-					
	ASD	<u>-.63</u> **	-					
Counting	Procedural	TD	.02	-				
	ASD	-.49*	.49*	-				
Conceptual	TD	-.12	.18	.62 ***	-			
	ASD	<u>-.66</u> ***	.58**	.61***	-			
Magnitude comparison	Overall RT	TD	-.56 **	.10	.06	-		
	ASD	-.09	-.30	.30	.20	-		
Overall accuracy	TD	-.08	-.15	.11	.39	.17	-	
	ASD	-.06	.29	.52**	.13	.04	-	
Estimation	Overall PAE	TD	.11	.16	-.14	-.14	<u>-.62</u> **	-.12
	ASD	.29	-.34	-.20	-.36	.11	.17	-
Arithmetic operations	TD	<u>-.67</u> ***	<u>-.33</u>	.50 **	.36	.34	-.01	-.14
	ASD	-.23	.27	.62***	.49**	.08	.14	-.21
FSIQ	TD	-.01	-.41	.30	.11	.04	.22	-.24
	ASD	.24	-.23	.13	.10	.17	.19	-.23
SRS	TD	-.17	.09	<u>-.37</u>	-.02	.08	.12	-.15
	ASD	.10	-.02	.20	.24	-.11	-.05	.23

Note. TD = typically developing; ASD = autism spectrum disorder; RT = reaction time; FSIQ = full scale IQ; SRS = raw score on *Social Responsiveness Scale*

* $p < .10$, ** $p < .05$, *** $p < .01$;); underlined correlations indicate a significantly stronger (absolute value) correlation than in the other group (Fisher r-to-z transformation, $p < .050$)



Verbal subitizing

Counting to an upper bound:
Count up to 6.

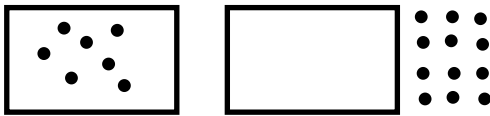
Counting from a lower bound:
Count from 3.

Counting from a lower to an upper bound:
Count from 5 up to 9.

Procedural counting

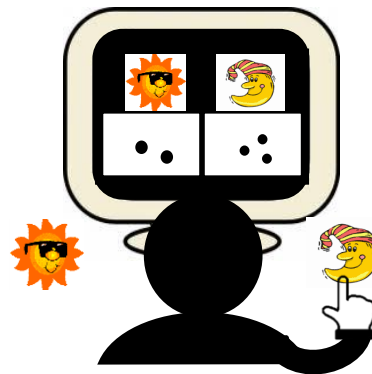


Count all objects. How many objects are there in total? How many objects are there if you start counting with the leftmost object in the array?

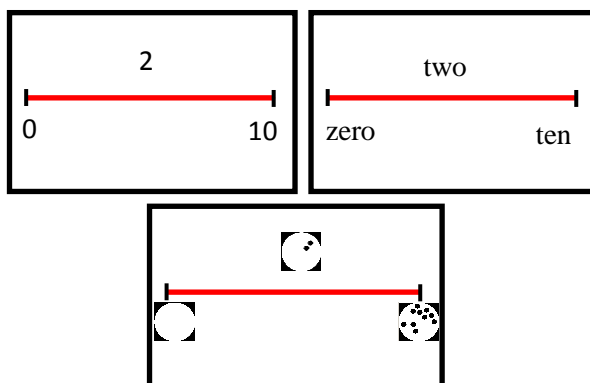


Put as many objects on this board as there are on this one.

Conceptual counting



Magnitude comparison



Estimation



*Here you can see two red balloons and three blue balloons.
How many balloons are there in total?*

Arithmetic operations

Figure 1

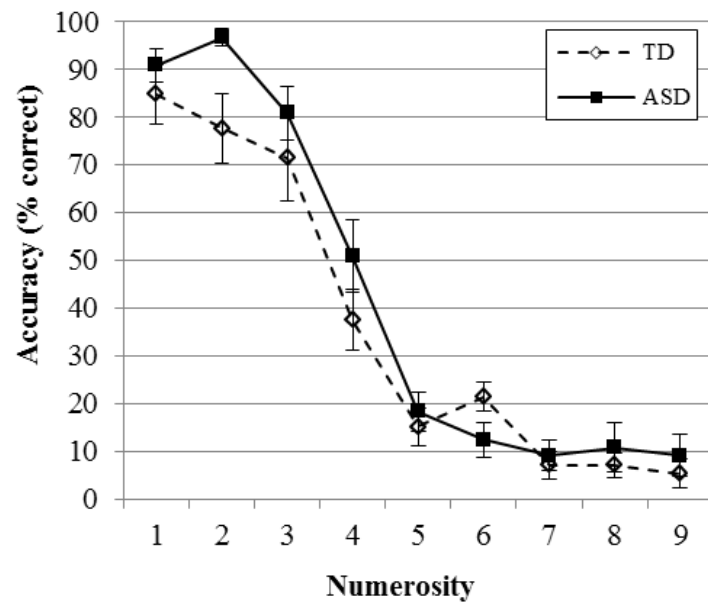


Figure 2

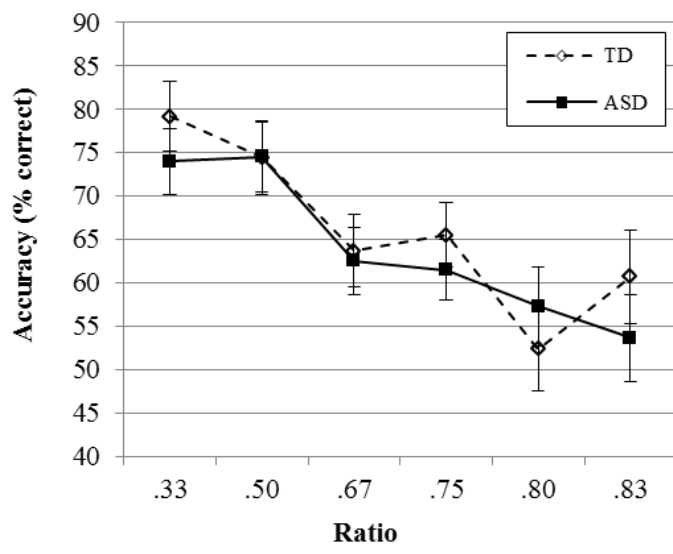


Figure 3

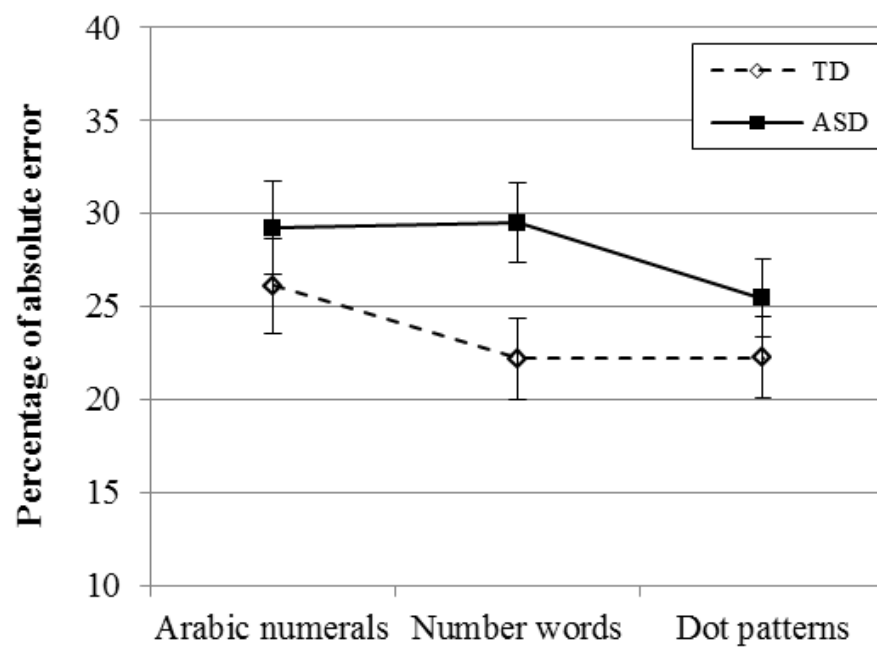


Figure 4