Screening for mathematical disabilities in kindergarten

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Abstract

Objective: This article is devoted to the potential early markers for mathematical learning disabilities in kindergarten in order to prevent children from falling further behind and from developing unrecognized mathematical disabilities later on.

Methods: Performances in preparatory arithmetic tasks were studied in 361 kindergartners focusing on differences between children at risk for mathematical disabilities and children who were at least moderately achieving in numerical arithmetic tasks.

Results: Evidence was found for several markers in kindergarten. Children at risk had lower scores on procedural counting knowledge, conceptual counting knowledge, seriation, classification, conservation and magnitude comparison tasks. Based on these kindergarten abilities, 77% of children who were at risk for mathematical disabilities could be detected.

Conclusion: Procedural and conceptual counting knowledge, seriation and classification skills and magnitude comparison abilities could possibly serve as powerful early screeners in the detection of mathematical disabilities.

Keywords: Screeners, mathematical learning disabilities, counting, seriation, classification, magnitude comparison

Introduction

Mathematical learning disabilities (MD) and several neurological disorders co-occur more frequently as comorbidities than would be expected by artificial causes (chance, sampling bias, population stratification, definitional overlap and rater biases). There can be little dispute that the presence of co-morbidity poses a serious challenge to existing assessment and comprehension of disorders [1]. This paper is devoted to the assessment of children at risk for mathematical disabilities, the co-morbidity with other disorders, the causes and sub-types of MD, the risk of under-estimating potentials because of math problems and the potential early markers for mathematical learning disabilities in order to prevent children from falling further behind and from developing unrecognized mathematical disabilities later on.

Mathematical learning disabilities (MD)

Although the prevalence of mathematical learning disabilities (MD) seems as high as the prevalence of reading disabilities, research interest for mathematical disabilities was very limited until now [1–3]. Nevertheless MD are common developmental disorders in childhood.

The term mathematics learning disability refers to a significant degree of impairment in the mathematics skill. The problems are not a part of the normal development and remediation or extra instruction does not lead to direct improvements (Resistance to Instruction). Secondly, the problems are not originated in mental retardation or impairments in general intelligence. The child’s level of attainment is substantially below that expected for a child of the same mental age. Furthermore, the difficulties are part of a developmental course. Problem onset must be early in the development of the child. Fourthly, the impairments can not be contributed to external factors that could provide sufficient evidence for scholastic failure. The fifth and last criterion states that the developmental disorders of scholastic skills are not directly due to uncorrected visual or hearing impairments [1, 4].

The prevalence of mathematics disabilities will vary depending on the criteria used to define the ‘substantially below’ performances [3, 5–8]. Most practitioners and researchers currently report a prevalence of mathematical disabilities between 3–14% of children [5–7].

MD are reported in relation to the Fragile X-syndrome and the developmental Gerstmann Syndrome [9]. Further, MD are reported in combination with Turner Syndrome [10], the Shprintzen syndrome [11], phenylketonuria (PKU) or neurofibromatosis type 1 (NFI) [4, 10], Klinefelter syndrome or disease of Duchenne [4, 12].
Seidenberg et al. [13] found an increased prevalence of mathematical disabilities in children with epilepsy and ADHD [4, 12]. Over 20% of the boys with ADHD were found to have MD [1, 4, 13, 14]. Also, many children with learning disabilities appeared to have developmental language disorders (DLD) when they were toddlers [1, 4, 15–17].

There are several models trying to describe or explain the mechanisms underlying quantity processing deficits in children with MD. Some models focus on immature counting and calculation strategies [7, 18, 19], slow serial elaboration [19, 20], deficits in the working memory or speed of processing [19, 21], problems retrieving from semantic long-term memory [7, 19], problems with visual spatial elaboration [7, 19, 22] and executive deficits [19, 23, 24]. However, some researchers consider the above-mentioned deficits as ‘higher’ order problems of children with MD, with an inborn neurological core deficit in the ‘number module’ [19, 21, 25] or in ‘number sense’ a term denoting the ability to picture and manipulate numerical magnitude on an internal number line [19, 26–29]. Impairments such as problems with subitizing and deficiencies in depicting or accessing magnitude information on the mental number line are considered by these researchers as ‘low-level’ symptoms consistent with the core deficit theory [4, 19].

Four sub-types of mathematical disabilities are currently found in scientific research: the sub-types based on procedural deficits, semantic memory deficits, visuospatial deficits and number knowledge deficits [4]. Procedural MD concerns a pattern of impairments in arithmetic procedures. Children (or adults) with this type of MD make a lot of mistakes in the use of arithmetic procedures and have difficulties in keeping track of the order of different steps in complex calculations. Mathematical performance is characterized by a time-lag in arithmetic procedures and one frequently sees the use of algorithms that are normally used by younger children. Geary [7] suggests that this kind of sub-type may be attributed to a left hemispheric of prefrontal dysfunction. Besides the procedural sub-type, a second pattern of MD is described as a semantic memory sub-type. Generally, arithmetic facts are not automatized, so simple arithmetic problems have to be calculated. This in turn means that much time is needed in order to give an answer. Sometimes people are able to retrieve numerical facts in the long-term memory. This, however, involves a great chance for not giving a correct solution. Because of those different patterns (retrieval from long-term memory and/or calculation), reaction times are very unstable and can vary from very quick to uttermost slowly. The PET-studies of Dehaene et al. [4, 27] show that those deficits may be localized in the left basal ganglia. This specific sub-type is expressed in a lower accuracy of mental calculation, slower speed of mental and written calculation, lower enumeration speed and difficulties with retrieving numerical facts [4, 28]. A third pattern of mathematical disabilities that is often described in literature contains a conjunction of visuospatial disabilities in the arithmetic domain. This sub-type is characterized by problems with insight in and notions of space [4, 29–33]. Those deficits are typically translated in difficulties in situating numbers on the number line, shuffling numbers in big figures and difficulties in the understanding of geometry [4, 21]. The consequences of those dysfunctions vary from difficulties in maintaining the decimal place and misalignment of digits in columns to inversions, reversals and even visual neglect. The profile is related to right hemispheric dysfunction [4, 7]. Mazzocco [10] reports remarkable higher prevalence of the visuospatial sub-type in girls with the fragile X-syndrome. A fourth sub-type concerns number knowledge deficits. People with this sort of MD miss the insight in the structure of the number system and do not know the specific positions for units, tens and hundreds. Those disabilities often emerge in number reading, number writing, number production and number knowledge. The existence of this kind of sub-type is confirmed by the findings of Cornoldi and colleagues [31, 33]. Ginsburg [34] points out that perhaps some children even can outgrow some mathematics learning disabilities and grow into others.

Most learning disabilities are not detected until in primary school [35]. However, empirical evidence suggests that the earlier one can detect children at risk, the more able one will be to prevent/avert learning difficulties later on [36]. The current interest in early predictors is encouraged by the hope that, if predictors and core deficits can be addressed as key components in remediation programmes, children may not fall further behind [37, 38].

Kindergarten markers for MD: The role of logical abilities

Some of the most described preparatory abilities in kindergartners are the logical abilities. The definition of these abilities is formulated in Piaget's basic work on the numerical development of the child [39]. In this work, ‘La genèse du nombre chez l’enfant’, Piaget postulated from a cognitive point of view that four logical abilities are conditional to the development of arithmetic, namely seriation, classification, conservation and inclusion.

Seriation is defined as the ability to sort a number of objects based on the differences on one or
more dimensions while ignoring the similarities. In contrast, classification is the ability to sort objects based on their similarities on one or more dimensions. Here children have to make abstraction of the differences. Once the child fluently knows how to serialize and to classify, it develops the knowledge that the number of objects in a collection only changes when one or more objects are added or removed. This concept in logical thinking is called conservation [39]. When children further develop and get older, they use this knowledge to make hierarchical classifications: they learn that numbers are series that contain each other. This is the inclusion principle and it can be seen as the highest form of classification [39, 40]. Piaget [40] argued that the full development of number comprehension is only possible when the child masters those four logical abilities.

Although a lot of criticism has been formulated on the theory of Piaget [41] the importance of the logical abilities is currently recognized. Yet researchers in the arithmetic domain are convinced that these abilities should no longer be seen as conditional to arithmetic development [6]. Many studies confirmed that logical abilities are important markers for the development of later arithmetic abilities. Even after controlling for differences in working memory, logical abilities in 6-year old children remained a strong predictor for arithmetic abilities 16 months later [42]. Seriation abilities in kindergarten have been found to play an important role in the prediction of arithmetic achievement in first grade [19, 42–44]. In addition, children who were successful in logical abilities tasks performed better on arithmetic tests and mastery of seriation abilities had the strongest predictive power [19, 43, 44]. Based on an intervention study it was found that children who were trained in logical reasoning made more progress in arithmetic abilities [6, 19, 44]. These studies support the hypothesis that good logical abilities could form a sound foundation for the numerical arithmetic development.

**Kindergarten markers for MD: The role of counting knowledge**

Besides the Piagetian operations, counting knowledge also seemed to be important in the development of arithmetic [36, 43–48]. Many researchers focused from different theoretical frameworks on the importance of counting knowledge in the development of later arithmetic abilities. In their follow-up study from preschool to second grade, Aunola et al. [47] found that counting knowledge was the best predictor for the initial level of math performance. Kindergartners who had no adequate and flexible counting knowledge developed deficient numeracy skills which resulted in arithmetic disabilities [6, 43–48].

Although a lot of research investigated counting as a unitary ability, Dowker [6] suggested that counting knowledge consists of procedural and conceptual aspects. Procedural and conceptual counting knowledge are strongly related to each other but they are described as two distinct skills children have to master [6, 19, 43–46]. Procedural knowledge is defined as children’s ability to perform an arithmetic task, for example, when a child can successfully determine that there are five objects in an array [48]. The knowledge of the sequence of counting words (the number row) is one of the most important procedural aspects of counting. This also includes the ability to count forward and backwards easily. Johansson [45] studied the role of procedural counting knowledge in a group of 126 children in kindergarten and first grade. He concluded that scores on procedural counting knowledge could predict the number and solving strategy of arithmetic problems. In their attempt to predict arithmetic abilities in second grade based on the abilities in kindergarten, Lepola et al. [49] found that only number sequence skills were a significant predictor. Even children of 9 or 10 years old sometimes showed difficulties in counting when this involved counting forwards and backwards from different starting numbers; and such children tended to have other arithmetical difficulties [50].

Besides the procedural aspect of counting knowledge, one clearly has to discern the conceptual counting knowledge. Conceptual knowledge reflects a child’s understanding of why a procedure works or whether a procedure is legitimate [48]. The conceptual aspect of counting knowledge contains the mastery of the counting principles. Gelman and Gallistel [51, 52] described five implicit conceptual principles in counting. The stable order principle (a) states that the order of number words must be invariant across counted sets. Every number word can only be attributed to one counted object (one-one-correspondence); (b). Once the cardinality principle (c) is acquired, children know that the value of the last number word represents the quantity of the counted objects. Mastery of the cardinality principle can be seen as one of the main foundations for a good development of several arithmetic abilities [4, 6]; The abstraction principle (d) states that objects of every kind can be counted [51, 52]. The last counting principle is the order-irrelevance principle (e). This holds that the object in a set can be counted in any sequence; Longitudinal research of Stock et al. [43] found that conceptual counting knowledge in kindergarten was an important predictor for later arithmetic abilities in first grade. Geary et al. [53] compared typical
children and children with arithmetical disabilities at the age of 6 and found that children of the latter group were more likely to make procedural errors in counting. Besides this, they found that some children with arithmetical disabilities still showed conceptual difficulties. Evidence was found for the importance of both aspects of counting knowledge, but it is clear that this study could not focus on only one aspect of counting without keeping an eye upon the other aspect. Moderate correlations between procedural and conceptual counting knowledge were reported [48].

Kindergarten markers for MD: The role of magnitude comparison

Recently, representation of number size was found to be also involved in numerical competence [19, 54]. This numerical skill is involved in subitizing and in magnitude comparison. Subitizing is the rapid apprehension of small numerosity, while magnitude comparison holds that children have to know which number in a pair is larger [36, 54, 55]. It was found that the larger the distance between the numbers and the smaller the magnitudes of the numbers, the faster and more accurate the answer on a magnitude comparison task was likely to be. Furthermore, performances on both magnitude comparison and subitizing tasks ameliorated with increasing age and experience [19, 56]. Magnitude comparison was found to be an important predictor of variations in MD [19, 57]. About one third of children with arithmetic disabilities had problems with magnitude comparison; children who had poor arithmetic performances in first grade had below-average skills to compare dot sets in kindergarten [58].

Objectives and research questions

Since MD is a comorbid disability in several neurological disorders and the earlier one recognizes MD the more able one is to prevent children from falling further behind and from developing extra difficulties later on, the study was set up to detect children at risk in kindergarten. In line with the work of Geary et al. [53], this study investigated if kindergarten abilities could discriminate between typically achieving children and children with at risk for MD.

Methods

Participants

This study has been carried out in a total group of 361 children (174 boys and 187 girls). All children were Caucasian native Dutch-speaking children living in the Flemish part of Belgium. In Belgium children attend kindergarten class for ~3 years and move to elementary classes in the year they turn 6 years old. Children had a mean age of 70.25 months (SD = 3.99).

Based on the numerical arithmetic tests in preschool, smaller samples of ‘children at risk for mathematical learning disabilities’ (MD) and ‘at least moderately achieving’ (MA) children were selected out of the original samples. The MD-children performed below the 11th percentile on the numerical arithmetic abilities test. The MA-children scored above the 50th percentile on this numerical sub-test. The MD-group consisted of 26 children, 167 children were selected as MA. At the end of grade 1 the 193 children were tested again. All MD-children still had below average mathematical skills and were described by the school teacher as children with ‘persistent MD’ in grade 1. All MA-children were according to the teacher children with persistent typical achieving.

A socio-economic status was derived from the total number of years of scholarship of the parents (starting from the beginning of elementary school). No significant differences in SES were found between the MA and MD groups, with M = 15.33 (SD = 2.36) for MA and M = 15.32 (SD = 3.16) for MD; F(1, 176) = 0.00, p = 0.98 for number of years of scholarship of mothers and M = 15.31 (SD = 2.85) for MA and M = 13.89 (SD = 2.85) for MD; F(1, 169) = 3.77, p = 0.05 for number of years of scholarship of fathers.

Measurements

Numerical arithmetic abilities. In order to have an estimate of the numerical arithmetic abilities of the children, this study used a numerical sub-test of the TEDI-MATH test battery [59]. The TEDI-MATH has been tested for conceptual accuracy and clinical relevance in previous studies [40, 57, 59]. The psychometric value was demonstrated on a sample of 550 Dutch speaking Belgian children from the second year of kindergarten to the third grade of primary school. The TEDI-MATH has proven to be a well validated and reliable instrument, values for Cronbach’s Alpha for the different sub-tests varies between 0.70–0.97.

The numerical arithmetic abilities test consisted of a series of simple arithmetic operations. First, the child was presented six arithmetic operations on pictures (e.g. ‘Here you see two red balloons and three blue balloons. How many balloons are there together?’). One point was given for a correct answer (maximum: 6 points). Cronbach’s alpha was 0.82. This study also presented 18 simple additions presented visually and orally in arithmetic format (e.g. ‘9 + 4 = . . . ’). When the child made five mistakes, this sub-test was interrupted. One point was given for a correct answer (maximum: 18
points). Cronbach’s alpha for this set of items was 0.95. Finally, children had to solve some simple word problems (e.g. ‘Dannie has two marbles. He wins two marbles. How many marbles does he have altogether now?’). This sub-test was interrupted after the child made five mistakes. One point was given for a correct answer (maximum: 12 points). Cronbach’s alpha was 0.84.

The total row item scores for this numerical arithmetic abilities test were summed and converted to z-scores in order to analyse the results. This numerical arithmetic abilities test has proven to have good convergent and divergent validity [60].

**Preparatory arithmetic abilities.** Four preparatory abilities were assessed: procedural counting knowledge, conceptual counting knowledge, logical abilities and magnitude comparison. In order to assess these preparatory abilities some sub-tests of the TEDI-MATH [59] were used.

**Procedural counting knowledge.** Procedural counting knowledge was assessed using accuracy in counting numbers and counting forward with an upper and/or lower bound. One point was given for a correct answer. As the task included eight items, the maximum total score was 8 points. This raw score was converted in a standardized raw score and in a percentile score based on the Flemish normative sample of the TEDI-MATH. The internal consistency of this task was good (Cronbach’s alpha = 0.73).

**Conceptual counting knowledge.** Conceptual counting knowledge was assessed with judgements about the validity of counting procedures. Children had to judge the counting of linear and random patterns of drawings and counters. To assess the abstraction principle, children had to count different kinds of objects that were presented in a heap. Furthermore, a child who counted a set of objects was asked ‘How many objects are there in total?’, or ‘How many objects are there if you start counting with the leftmost object in the array?’ When children had to count again to answer, they did not gain any points, as this was considered to represent good procedural knowledge, but a lack of understanding of the counting principles of Gelman and Gallistel [51, 52]. One point was given for a correct answer with a correct motivation. The maximum total score was 13 points. This raw score was converted in a standardized raw score and in a percentile score based on the Flemish normative sample of the TEDI-MATH. The internal consistency of this task was good (Cronbach’s alpha = 0.85).

**Logical abilities.** Logical abilities were assessed using three different tasks. Children had to seriate numbers (e.g. ‘Sort the cards from the one with the fewest trees to the one with the most trees’). The maximum score was 3 points. Children had to make groups of cards in order to assess the classification of numbers (e.g. ‘Make groups with the cards that go together’). The maximum score was 3 points. Two rows of six counters were used to test the conservation of numbers (maximum: 4 points). One point was given for a correct answer with a correct logical motivation. The raw scores on the logical abilities tasks were converted in standardized raw scores and in percentile scores based on the Flemish normative sample of the TEDI-MATH. The internal consistency of the three tasks were good with Cronbach’s alpha of 0.68, 0.73 and 0.85, respectively.

**Magnitude comparison.** Magnitude comparison was assessed by comparison of dot sets. Children were asked where they saw most dots. One point was given for a correct answer. As the task included six items, the maximum score was 6 points. This raw score was converted in a standardized raw score and in a percentile score based on the Flemish normative sample of the TEDI-MATH. The internal consistency of this task was good (Cronbach’s alpha = 0.79).

**Procedure**

The children were recruited in different schools. Parents received a letter with the explanation of the research and submitted informed consent in order to participate. Children were tested during school time in a separate and quiet room. Children were tested all individually for ~40 minutes, with a short break in between. All tasks were tested at the same moment in the month of May of the last kindergarten class. The test leaders all received training in the assessment and interpretation of the tests. After completion of the test procedure, all the parents of the children received individual feedback on the results of their children. Follow-up assessment with two arithmetic tests was conducted in first grade.

**Results**

A multivariate analysis of variance (MANOVA) was conducted to investigate if children at risk for mathematical disabilities (MD) and children with at least moderate (MA) numerical arithmetic abilities can be differentiated on their kindergarten abilities. Six preparatory abilities were entered as dependent variables: procedural counting knowledge,
conceptual counting knowledge, seriation, classification, conservation and magnitude comparison. No significant differences were found when using standardized raw scores or percentile scores in the analyses. Percentile scores are described in order to link the scores of this sample to the scores of the stratified normative sample and to obtain an easier clinical interpretation of the findings.

The MANOVA was significant on the multivariate level, $F(6, 186) = 29.73$, $p < 0.001$. The mean scores and standard deviations of the dependent variables for the two groups are shown in Table I. On the univariate level there were significant differences between the groups for all six preparatory kindergarten abilities. The respective $F$-values are reported in Table I. As presented in Table I, the MA group performed significantly better than the MD group on procedural counting knowledge, conceptual counting knowledge, seriation, classification, conservation and magnitude estimation.

In order to find out whether it was possible to classify children in the MD or the MA group based on the kindergarten skills (procedural counting knowledge, conceptual counting knowledge, seriation, classification, conservation and magnitude comparison), a discriminant analysis procedure was performed. The Fisher’s linear discriminant function was used to investigate the accurateness of the predicted classifications. The overall Wilks’ lambda was significant, $\Lambda = 0.51$, $\chi^2 (6, n = 193) = 126.41$, $p < 0.001$, indicating that overall the preparatory abilities differentiated among the MD and MA group. In Table I the standardized weights of the predictors were presented. Based on these coefficients, procedural counting knowledge and seriation demonstrated the strongest relationships with arithmetic abilities.

Based on the scores for these six kindergarten predictors, 93.8% of the children were classified correctly into the MD or MA group, whereas 92.7% of the cross-validated grouped cases were classified correctly. Based on the six kindergarten abilities, 76.9% of low numerical achieving children and 96.4% of the at least moderately numerical achievers were classified correctly. In order to take into account chance agreement, a kappa coefficient was computed and obtained a value of 0.73, indicating a good prediction.

**Conclusion**

This article looked for differences in kindergarten skills to detect children at risk for MD. The results showed that there were indeed important differences in the preparatory abilities in kindergarten. The MD children did significantly worse on procedural counting, conceptual counting, seriation, classification, conservation and magnitude comparison tasks than children who had at least moderate scores in numerical arithmetic tasks.

Based on these six preparatory abilities, more than 90% of children could be classified correctly as ‘at risk’ for MD or at least moderately achieving in numerical arithmetic. Especially procedural counting knowledge and seriation seemed to have an important role in the prediction of numerical arithmetic abilities. The classification results for the at least moderately achieving children were better than the classification results for children at risk for MD, but more than three of four MD-children could be detected based on the kindergarten abilities.

These results underline the important role of counting knowledge, logical abilities and magnitude comparison in the development of numerical arithmetic abilities, even in kindergarten. These results implicate that it is not only important to assess how accurate young children can count (procedural knowledge) but also how they master the counting principles of Gallistel and Gelman [51, 52]. The Piagetian model [39, 40] had some value added since low achieving children had lower scores than at least moderately achieving children on seriation, classification and conservation tasks. Seriation was demonstrated to be a possible important
kindergarten screener. Furthermore, this study confirmed that children at risk for MD did worse on magnitude comparison tasks than at least average performing peers.

This study however had a few limitations. Although there is evidence for the importance of speed of counting [48], only accuracy on counting tasks was assessed in the current design. Furthermore, context variables such as home and school environment, learning packages and parental involvement [61] should be included in order to have full sight on the numerical arithmetic development of these children. Finally, it might be interesting to see if a controlled kindergarten intervention focusing on these preparatory abilities in children at risk can prevent learning difficulties in elementary school. Further longitudinal research is needed in order to search for confirmation or disconfirmation of the conclusions made. Such studies are currently being analysed.

Summarizing, the results indicated that kindergartners at risk for MD tend already to have lower scores on kindergarten tasks than children who are at least moderately achieving in numerical arithmetic. Evidence was found for differences in procedural counting knowledge, conceptual counting knowledge, seriation, classification, conservation and magnitude comparison abilities. These preparatory abilities can be seen as basic stones for the later numerical arithmetic development and could possibly serve as powerful early markers in the detection or screening of MD. Clinicians should not neglect the results of seriation, classification and conservation tasks as well as of procedural and conceptual counting and magnitude comparison tasks in preschool and might include these measures in an assessment battery for children at-risk. The results of the current study highlight the relationship of these tasks with the numerical abilities of these young children. Kindergarten tests should therefore include those aspects.

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References


