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Detecting Children With Arithmetic Disabilities From Kindergarten: Evidence From a 3-Year Longitudinal Study on the Role of Preparatory Arithmetic Abilities

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Abstract

In a 3-year longitudinal study, 471 children were classified, based on their performances on arithmetic tests in first and second grade, as having persistent arithmetic disabilities (AD), persistent low achieving (LA), persistent typical achieving, inconsistent arithmetic disabilities (DF1), or inconsistent low achieving in arithmetic. Significant differences in the performances on the magnitude comparison in kindergarten (at age 5–6) were found between the AD and LA and between the AD and DF1 groups. Furthermore, the percentage of true-positive AD children (at age 7–8) correctly diagnosed in kindergarten by combination of procedural counting, conceptual counting, and magnitude comparison tasks was 87.50%. When composing clinical samples, researchers should pay attention when stipulating restrictive or lenient cutoffs for arithmetic disabilities and select children based on their scores in 2 consecutive years, because the results of studies on persistent low achievers or children with inconsistent disabilities cannot be generalized to children with persistent arithmetic disabilities.

Keywords

intervention, early identification/intervention, arithmetic

Early arithmetic abilities have been found to be the strongest predictor of later school achievement (e.g., DiPerna, Lei, & Reid, 2007; Duncan et al., 2007; Muldoon, Lewis, & Francis, 2007; Stock, Desoete, & Roeyers, in press; Teisl, Mazzocco, & Myers, 2001). Because arithmetical disabilities are persistent (Shalev, Manor, & Gross-Tsur, 2005), it would be interesting to recognize vulnerable young children early in order to prevent children from falling further behind and from developing arithmetic difficulties later on (Coleman, Buysse, & Neitzel, 2006; Gersten, Jordan, & Flojo, 2005; Pasnak, Cooke, & Hendricks, 2006). In addition, the first step in a response-to-intervention (RTI) prevention model is determining children who are at risk for developing arithmetic learning disabilities (e.g., Fuchs et al., 2007; Kavale & Spaulding, 2008). Identification of children at risk in kindergarten permits children to participate in prevention services before the onset of substantial deficits (Fuchs et al., 2007).

There is not yet a consensus regarding which of the early math predictors are uniquely associated with early responses to formal math instruction in kindergarten, first-grade, and second-grade children. Some of the traditional preparatory arithmetic abilities in kindergartners are the Piagetian logical abilities (Nunes & Bryant, 1996; Piaget, 1965). Besides the Piagetian-type tasks, counting knowledge also seems to be associated with early responses to formal math instruction (Baroody, 1992; Frank, 1989; Gersten et al., 2005; Johansson, 2005; Sophian, 1992; Van De Rijt & Van Luit, 1999). Moreover, representation of number size was found to be involved in numerical competence as well (Jordan, Kaplan, Olah, & Locuniak, 2006). In the present study, we sought to combine the classical Piagetian-type tasks with other post-Piagetian domain-specific measures such as counting knowledge and insight in magnitude comparison and determine the contribution of intelligence as predictors for children at risk. The purpose of this study was to examine differences between children with persistent arithmetic disabilities (AD) and children in the low-achiever (LA) group and the typical-achiever (TA) group with respect to theoretically relevant predictors and determine the accuracy with which the predictors could be used as screeners to identity children with math difficulties.

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First, the main findings on Piagetian-type tasks, counting abilities, and magnitude comparison as important, although certainly not mutually exclusive, preparatory arithmetic abilities, controlling for the role of intelligence, is addressed. Next, we focus on the implications of the use of different selection criteria in order to define children with arithmetic disabilities. In the last section, the objectives of this study are specified.

Preparatory Arithmetic Abilities

Piagetian-Type Tasks. Piaget and Szeminska (1941) postulated 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 in one or more dimensions while ignoring the similarities. In contrast, *classification* is the ability to sort objects based on their similarities in one or more dimensions. Here, children have to make abstractions of the differences. In 1959, Piaget and Inhelder stated that the coordination of seriation and classification is needed for the comprehension that 4 is included in 5, whereas 5 itself is included in 6 (Grégoire, 2005).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 (Piaget & Szeminska, 1941). Once the child is confident in the knowledge that the number of objects in a collection only changes when one or more objects is added or removed, he or she masters the conservation principle (Piaget & Szeminska, 1941). Piaget (1965) argued that the full development of number comprehension is only possible when the child masters these four logical abilities. However, Piaget ignored the importance of counting.

Since the publication of the work of Piaget, several neo-Piagetian researchers have questioned the causality of seriation and classification for understanding numbers (e.g., Dumont, 1994; Lourenço & Machado, 1996) and have stated that counting is the best predictor for early arithmetic performances. Nevertheless, other studies have revealed that seriation assessed in kindergarten is related to arithmetic achievement in Grade 1 (e.g., Grégoire, 2005; Kingma, 1984; Stock, Desoete, & Roeyers, 2006) and Grade 2 (Grégoire, 2005), and children adequately solving classification tasks in kindergarten perform better in arithmetic tasks in Grades l and 2 (Grégoire, 2005). Many studies have confirmed that logical abilities are important markers for the development of arithmetic abilities. Even after controlling for differences in working memory, logical abilities in 6-year-old children remain a strong predictor for arithmetic abilities 16 months later (Nunes et al., 2007).

Post-Piagetian Counting Knowledge. Since the 1980s, there has been considerable interest in counting as a neo-Piagetian milestone in the development of an understanding of numbers (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Chard et al., 2005; Fuson, 1988; Le Corre, Van de Walle, Brannon, & Carey, 2006). Dumont (1994) hypothesized that counting predicted ordinality (outcome measure of seriation) and cardinality (outcome measure of classification). Moreover, it is obvious that early mathematics involves counting (Wynn, 1990). For example in the "count all" or "sum" strategy, the child first counts each collection and then counts the combination of two collections starting from 1 (i.e., 2 + 5 = 1, 2 . . . 1, 2, 3, 4, 5 . . . 1, 2, 3, 4, 5, 6, 7). As practice increases, older children use more effective backup strategies (Barrouillet & Lepine, 2005). In addition, counting can be seen as the foundation for strategies such as subtraction (Le Fevre et al., 2006) and multiplication (Blöte, Lieffering, & Ouwehand, 2006).

Although a lot of research looked into counting as a unitary ability, Dowker (2005) suggested that counting knowledge consists of procedural and conceptual aspects. *Procedural knowledge* is defined as a child's ability to perform a counting task, for example, when a child can successfully determine that there are five objects in an array (Le Fevre et al., 2006). *Conceptual counting knowledge* reflects a child's understanding of why a procedure works or whether a procedure is legitimate. It demonstrates the understanding of the essential counting principles: the stable order principle, the one-to-one correspondence principle, and the cardinality principle (Gallistel & Gelman, 1990; Gelman, 1990; Le Fevre et al., 2006; Wynn, 1992).

Many researchers, approaching from different theoretical frameworks, focused on the importance of procedural and conceptual counting knowledge in the development of arithmetic abilities (Baroody, 1992; Frank, 1989; Fuchs et al., 2007; Gersten et al., 2005; Johansson, 2005; Le Corre et al., 2006; Le Fevre et al., 2006; Sophian, 1992; Van de Rijt & Van Luit, 1999). In their longitudinal study from preschool to second grade, Aunola and colleagues (2004) found that counting ability was the best predictor of the initial level of arithmetic performance. It has been found that children's basic conceptual understanding of how to count objects and their knowledge of the order of numbers play an important role in later arithmetic performance. Mastery of conceptual knowledge allows children to devote attentional resources to more complex arithmetic problem solving (Aunola et al., 2004).

There are a lot of studies on the counting skills of participants with arithmetic disabilities (e.g., Geary, 2004; Jordan, Hanich, & Kaplan, 2003). Dowker (2005) showed that children who had difficulties in any particular aspect of counting had overall below-average mathematical performances. Fuchs et al. (2007) included number identification/counting as one of the screening measures for forecasting math disabilities at the end of second grade. In addition, it was shown that toddlers who lacked adequate and flexible counting knowledge went on to develop deficient numeracy skills, which resulted in arithmetic disabilities (Aunola et al., 2004; Gersten et al., 2005). Furthermore, Geary, Bow-Thomas, and Yao (1992) found that small children with arithmetic disabilities were more likely to make procedural errors in counting and still had considerable conceptual difficulties at the age of 6. Desoete and Grégoire (2007) also showed that children with arithmetic disabilities in Grade 1 already had encountered problems on numeration in nursery school. They also found some evidence of dissociation of numerical abilities in children with arithmetic disabilities in Grade 3. Certain skills appeared to be developed, whereas others were not, which made it necessary to investigate them separately and independent of one another. About 13% of the children with arithmetic disabilities still had processing deficits in number sequence and cardinality skills in Grade 3. About 67% of these children in Grade 3 had a lack of conceptual knowledge. Finally, in this field of research, Porter (1998) contributed the finding that the acquisition of procedural counting knowledge did not automatically lead to the development of conceptual understanding of counting in children with arithmetic disabilities. Taking into account the complex nature of mathematical problem solving, it may be useful to assess procedural as well as conceptual counting procedures in young children at risk. However most post-Piagetian researchers have ignored the importance of seriation and classification and have focused only counting skills.

*Magnitude Comparison as a "Core" Deficit? Recently, number sense and representation of number size were also found to be involved in numerical competence (*e.g., Berch, 2005; Butterworth, 2005; Gersten et al., 2005; Griffin, 2004; Jordan at al., 2003; Jordan, Kaplan, Olah, & Locuniak, 2006). For a description of the complexity of number sense, we refer to Berch (2005), who reviewed the relevant literature and pointed out that processing number sense allows a child to achieve problem solving from understanding the meaning of numbers to developing strategies; from making number comparisons to creating procedures for operating numbers; and from integrating her or his knowledge to interpret information. Number sense is involved in *subitizing* and in *magnitude comparison*. Subitizing is the rapid apprehension of small numerosity (Kaufman, Lord, Reese, & Volkmann, 1949; Nan, Knösche, & Luo, 2006), whereas magnitude comparison holds that children have to know which number in a pair is larger (Desoete, Ceulemans, Roeyers, & Huylebroeck, 2009; Gersten & Chard, 1999; Hannula & Lehtinen, 2005; Xu & Spelke, 2000). 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 (Dehaene, 1997; Dehaene, Bossini, & Giraux, 1993; Gevers, Lammertyn, Notebaert, Verguts, & Fias, 2006; Zhou, Chen, Chen, & Dong, 2008). Furthermore, performances on both magnitude comparison and subitizing tasks improved with increasing age and experience (Laski & Siegler, 2007; Xu, 2003).

Some researchers explain the problems of children with arithmetic disabilities as results of a "core" deficit in *number sense,* a term denoting the ability to picture and manipulate numerical magnitude on an internal number line (e.g., Gersten et al., 2005; Holloway & Ansari, 2009; Landerl, Bevan, & Butterworth, 2004; von Aster & Shalev, 2007). Magnitude comparison was found to be an important predictor of variation in arithmetic abilities (Durand, Hulme, Larkin, & Snowling, 2005).

There are far fewer studies on number sense skills than on counting knowledge of children with arithmetic disabilities. However, Reeve and Reynolds (2004) found that 6% of a randomly selected group of children did not subitize (they called them the "nonsubitizers"). These children were followed in a longitudinal design, revealing that nonsubitizers were slower in reading three-digit numbers in comparison to the so-called slow or fast subitizers. These results were repeated the next year as well. The authors, however, did not report whether these nonsubitizers actually developed arithmetic disabilities. The importance of subitizing in arithmetic disabilities was pointed out by Koontz and Berch (1996), who found that children with arithmetic disabilities were slower to process numbers and slower in subitizing tasks in comparison to children without arithmetic disabilities. This finding was confirmed by Landerl and colleagues (2004) and by Rousselle and Noël (2007) when they found that children with arithmetic disabilities were slower at numerical differentiation in comparison to children in control groups and that they showed deficits in subitizing. However, not all children with arithmetic disabilities were found to have subitizing problems. Desoete and Grégoire (2007) found a severe subitizing deficit in 33% of the 30 8½-year-old children with average intelligence with a clinical diagnosis of arithmetic disabilities in Flanders. Fischer, Gebhart, and Hartnegg (2008) found that between 43% and 79% of participants in the age range of 7 to 17 years with arithmetic disabilities performed below the 16th percentile of the peer control groups on subitizing tasks.

Early Arithmetic Skills. Initial arithmetic can be seen as a broad domain of various arithmetical achievement and numerical facility skills (Dowker, 2005). Arithmetical achievement is needed to convert linguistic and numerical information into math equations and algorithms, to understand mathematical concepts and operations, and to identify and select appropriate strategies for solving computation and word problems. In addition, by executing arithmetic problems repetitively, basic number facts (e.g., $6 + 2 = 8$) are retained in long-term memory and automatically retrieved if needed. Children with arithmetic disabilities often have problems in the area of automaticity. They lack numerical facility and do not know basic number facts by heart (Geary & Hoard, 2005; Jordan, Levine, & Huttenlocher, 1995).

Intelligence. Often, an IQ assessment serves as an indicator for the general level of achievement (American Psychiatric Association, 2000; Dickerson Mayes, Calhoun, Bixler, & Zimmerman, 2009; Gross-Tsur, Manor, & Shalev, 1996). Recent studies found a correlation of .50 between arithmetical abilities and intelligence (Desoete, 2008; Kort et al., 2002; Ruijssenaars, Van Luit, & Van Lieshout, 2004).

The present study aims to look at the possible group differences in intelligence among children with arithmetic disabilities, children who are low achieving, and children who are typical achievers so as to not confound those group differences in the assessment of arithmetic achievement and disabilities.

Criteria in Arithmetic Disabilities Research

Seriation, classification, procedural counting knowledge, conceptual counting knowledge, and magnitude comparison as preparatory arithmetic abilities have shown to be promising markers for the early detection of children with arithmetic disabilities. Yet, the lack of a unified set of distinct criteria that describes arithmetic disabilities (Mazzocco, 2001, 2005; Mazzocco & Myers, 2003; Stock et al., 2006; Vaughn & Fuchs, 2003) has profound implications for research that aims to detect children with these disabilities.

The use of divergent selection criteria in the recruitment of research samples based on cutoffs ranging from the 3rd percentile to even the 45th percentile (American Psychiatric Association, 2000; Geary, 2004; Klauer, 1992; Kosc, 1974; Mazzocco, 2001; Stock et al., 2006) may have conflated children with severe and mild forms of arithmetic disability (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Mazzocco, Devlin, & McKenney, 2008). Murphy, Mazzocco, Hanich, and Early (2007) revealed differences between children with a severe form of disability (using restrictive criteria), children with a mild form of disability (using lenient criteria), and children with a math performance exceeding the 25th percentile. Children selected with restrictive or those selected with lenient criteria showed different arithmetic skills in kindergarten, with the former having more deficient arithmetic abilities than the children with a mild form of disability. Mazzocco et al. (2008) found that children with a severe form of disability showed qualitatively different profiles in fact-retrieval performances when compared to typically achieving children, whereas the differences between children with a mild form of disability and typically achieving children were of a quantitative turn. Geary et al. (2007) revealed that children with a severe disability had a severe math cognition deficit and an underlying deficit in working memory and speed of processing. The groups with a mild disability had more subtle deficits in a few math domains. The variability and wide array of selection criteria may have dispelled a clear and accurate idea of the nature of the disability, complicating identification, diagnosis, treatment, and remediation of children with arithmetic disabilities (Geary et al., 2007; Hammill, 1990; Mazzocco et al., 2008; Murphy et al., 2007).

Finally, it is important to consider consistency in performance over time (Hanley, 2005; Mazzocco & Myers, 2003). In the *status model,* children are identified having arithmetic disabilities based on an assessment at a single testing point (Fletcher, Denton, & Francis, 2005). However, because arithmetic capacities are dynamic, there is much variability in the developmental process (Shalev, 2004), and test scores will fluctuate around a cut point, which necessitates repeated testing (Fletcher et al., 2005). To be sure of the persistence of disabilities even though remediation has taken place, recent studies have often selected children based on their scores in 2 or more consecutive years. Geary (2004) used the cutoff criterion of the 25th percentile but warranted that only children who had scores across successive academic years beneath this cutoff may have a diagnosis of arithmetic disabilities. The implementation of such a *fluctuation model* and *persistence criterion* is important because it was found that performances in children meeting criteria for arithmetic disabilities at one point in time could not be generalized to children who successively meet criteria year after year although adequate instruction took place (Fletcher et al., 2005; Mazzocco, 2001; Murphy et al., 2007). This persistence criterion is also included in the recent emphasis on RTI for defining arithmetic disabilities (e.g., Fuchs et al., 2007). When children's abilities are not enhanced in arithmetic performance, even though they got special task-specific instruction, they are defined, according to the RTI principle, as children with arithmetic disabilities.

Objectives and Research Questions

Because there is not yet a consensus regarding which type of predictors are uniquely associated with early arithmetic performances, in this study Piagetian and post-Piagetian ideas are combined. In addition, magnitude comparison was added because this might be a core deficit in children with arithmetic disabilities. The combination of the classical Piagetian-type tasks with other measures of conceptual and procedural knowledge and magnitude comparison, without confounding group differences in intelligence, is a unique and interesting aspect of this study.

The first purpose of the current study was to investigate, in line with Mazzocco and Thompson (2005), kindergarten predictors (at age 5–6) of arithmetic performance in Grade 1 (at age 6–7) and Grade 2 (at age 7–8). Furthermore, in this 3-year longitudinal study, it was questioned if it was possible to detect children with persistent arithmetic disabilities in Grade 2 based on the preparatory arithmetic abilities in kindergarten.

Moreover, in line with Murphy et al. (2007), it was studied whether the characteristics of children with arithmetic disabilities vary as a function of the cutoff criterion used to define

Table 1. Descriptive Information Based on the Subsamples: Means and Standard Deviations (in parentheses)

	AD	LA	TA	DF1	DF2	$F(4, 459)$
Socioeconomic status: Number of years of scholarship of the mother	14.86 (2.44)	14.27 (2.60)	14.94 (2.35)	14.38 (2.48)	15.14 (2.59)	1.179, p = .319
Socioeconomic status: Number of years of scholarship of the father	13.57 (2.77)	14.12 (3.44)	14.65 (2.91)	14.30 (2.58)	14.03 (2.19)	0.996, p = .409
Intelligence (TIQ)	96.12 (13.99)	100.44 (16.28)	101.41 (12.75)	97.96 (15.22)	99.67 (15.22)	1.399, p = .233

Note: AD = persistent arithmetic disabilities group; LA = persistent low-achieving group; TA = persistent typically achieving group; DF1 = inconsistent arithmetic disability group; DF2 = inconsistent low-achieving group; TIQ = total intelligence quotient.

the disabilities. The research question of whether it was possible to find differences in kindergarten characteristics between groups based on severity or between children with persistent arithmetic disabilities, children who are persistent low achievers, and children who are persistent typical achievers is addressed.

Finally, in line with Fletcher et al. (2005), contrasting the status model with the fluctuation model, the kindergarten characteristics of children with persistent arithmetic disabilities based on an assessment at two testing points and the scores of children with inconsistent arithmetic disabilities and clinical scores at one testing point are compared.

Method

Participants

Participants were 471 children (227 boys and 244 girls) who entered the study in the last year of kindergarten (age 5–6) and completed data collection in first grade (age 6–7) and second grade (age 7–8). The children had a mean age of 70.02 months (SD = 4.01 months) and attended on average 7.42 months (SD = 1.03 months) of school in the last kindergarten class when tested the first time. The follow-up testing was in Grade 1 (M = 82.02 months) and in Grade 2 (M = 94.02 months). In the present study, the data of 464 of these children (225 boys and 239 girls) were analyzed. Only children with at least average intelligence were included in the analyses. All children were Caucasian and native Dutch speaking, living in the Flemish part of Belgium. In Belgium, children attend kindergarten class for about 3 years (from when they turn 2 years 6 months old) and move to elementary classes in the year they turn 6.

To separate groups based on potential severity, three groups of children (AD, LA, TA) participated in this study (n = 319), based on an assessment and consistent achievement on at least two testing points (the first testing took place in Grade 1; the second testing took place in Grade 2). Children were classified in Grade 2 retrospectively as having arithmetic disabilities (AD) if they scored below or at the 10th percentile on at least one of the arithmetic achievement tests, both in first and second grade (n = 10 boys and 6 girls). Children who scored in the 11th to 25th percentile on at least one of the arithmetic achievement tests, both in first and second grade, were classified as low achieving (LA; n = 14 boys and 13 girls). The third group consisted of typical achievers (TA; n = 154 boys, 165 girls), or children who scored above the 25th percentile on all arithmetic achievement tests in both grades.

To compare the status model versus the fluctuation model, we explored our data set for children with fluctuating test scores and within-subject inconsistency on poor arithmetic achievement across the primary school-age years. To be accepted in our sample as children with fluctuating scores, children had to belong to the group called *severe arithmetic difficulties* (DF1) or to the group called *mild arithmetic difficulties* (DF2). The DF1 group was a group of 26 boys and 39 girls performing above or at the 10th percentile in one grade (so they would have been classified as into the AD group based on an assessment at a single testing point) and above the 25th percentile in the other grade (so they belonged to the TA group based on this single testing). The DF2 group was the group of 21 boys and 16 girls who scored between the 11th and 25th percentile in one grade and above the 25th percentile in the other grade.

Socioeconomic status (SES) was derived from the total number of years of scholarship of the parents (starting from the beginning of elementary school), with a mean of 14.84 years (SD = 2.41 years) for mothers and 14.48 years (SD = 2.85 years) for fathers. No significant differences in SES were found between the AD, LA, TA, DF1, and DF2 groups (see Table 1).

Materials

All children were tested in kindergarten on their preparatory arithmetic abilities. Follow-up assessment with two arithmetic tests was conducted in first and second grade, and intellectual abilities were tested in second grade.

Preparatory Arithmetic Abilities in Kindergarten. All preparatory arithmetic abilities were tested with different subtests of the *Test for the Diagnosis of Mathematical Competencies* (TEDI-MATH; Grégoire, Noel, & Van Nieuwenhoven, 2004). The TEDI-MATH is an individual assessment battery that was constructed to detect arithmetic disabilities. The manual suggests using scores below the 25th percentile as clinical cutoff scores for children at risk. Important basic works for the construction of the test were the theory on logic thinking of Piaget (Piaget, 1965; Piaget & Szeminska, 1941), the research on counting of Gelman and Gallistel (1978) and Fuson and colleagues (e.g., Fuson, 1988), and the research of Geary (e.g., Geary, 1994) on the development of arithmetic abilities. The TEDI-MATH has been tested for conceptual accuracy and clinical relevance in previous studies (e.g., Desoete & Grégoire, 2007; Stock et al., 2007). 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 (Desoete, 2006, 2007a, 2007b) and reliable instrument; Cronbach's alpha values for the different subtests vary between .70 and .97 (Grégoire et al., 2004). The predictive value has been established in a longitudinal study of 82 children from kindergarten until grade 1 (Desoete & Grégoire, 2007) and on 240 children assessed in Grades 1, 2, or 3 with TEDI-MATH and reassessed 2 years later with arithmetic tasks (Desoete, 2007b; Desoete, Stock, Schepens, Baeyens, & Roeyers, 2009). In addition, the Flemish data were confirmed with similar data from the French-speaking part of Belgium and France (Desoete, Roeyers, Schittekatte, & Grégoire, 2006). Counting knowledge included procedural and conceptual knowledge of counting.

Procedural knowledge of counting. Procedural knowledge of counting was assessed using accuracy in counting numbers, counting forward to an upper bound (e.g., "Count up to 6"), counting forward from a lower bound (e.g., "Count from 3"), and counting forward with an upper and lower bound (e.g., "Count from 5 up to 9"; see the appendix). One point was given for a correct answer without helping the child. The task included 13 items; the maximum total score was 14 points. The total row item scores were summed and converted to z scores. In addition, percentile scores were computed to link the scores of our sample to the scores of the stratified normative sample and to obtain an easier clinical interpretation of the findings. The internal consistency of this task was good (Cronbach's $\alpha = .73$).

Conceptual knowledge of counting. Conceptual knowledge of counting was assessed with judgments about the validity of counting procedures. Children had to judge the counting of linear and random patterns of drawings and counters (see the appendix). 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 have to count again to answer, they did not gain any points, as this is considered to represent good procedural knowledge but a lack of understanding of the counting principles of Gelman and Gallistel (1978). One point was given for a correct answer with a correct motivation (e.g., You did not add objects, so the number of objects has not changed). The maximum total score was 13 points. The total row item scores were summed and converted to z scores. In addition, percentile scores were computed to link the scores of our sample to the scores of the stratified normative sample. The internal consistency of this task was good (Cronbach's $\alpha = .85$).

Logical abilities. Logical abilities were assessed using two different tasks (see the appendix). Children had to seriate numbers (e.g., "Sort the [six] 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 nine cards in order to assess the classification of numbers (e.g., "Make [three] groups with the cards that go together"). The maximum score was 3 points. The total row item scores were summed and converted to z scores. In addition, percentile scores were computed to link the scores of our sample to the scores of the stratified normative sample. The internal consistency of the two tasks were good, with Cronbach's alphas of .68 and .73, respectively.

Magnitude comparison. Magnitude comparison (see the appendix) was assessed by comparison of dot sets (e.g., 4 dots vs. 6 dots or 7 dots vs. 2 dots). 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. The total row item scores were summed and converted to z scores in order to analyze the results. In addition, percentile scores were computed to link the scores of our sample to the scores of the stratified normative sample. The internal consistency of this task was good (Cronbach's $\alpha = .79$).

Arithmetic Tests in First and Second Grade. To have a full sight on the arithmetic abilities of children in first and second grade, two arithmetic tests were used: the *Kortrijk Arithmetic Test–Revised* (*Kortrijkse Rekentest Revision,* KRT-R; Baudonck et al., 2006) and the *Arithmetic Number Facts Test* (*Tempotest Rekenen,* TTR; De Vos, 1992).

The KRT-R (Baudonck et al., 2006) is a standardized test on arithmetical achievement that requires that children solve 30 mental arithmetic problems (e.g., 16 – 12 = __) and 30 number knowledge tasks (e.g., 1 more than 3 is __) in first grade; children in second grade received 30 and 25 tasks, respectively. The KRT-R is frequently used in Flemish education as a measure of arithmetic achievement (e.g., Desoete & Grégoire, 2007; Desoete, Roeyers, & De Clercq, 2004). The test results in a score for mental computation, a score for number system knowledge, and a total score. The row item scores were converted to percentile scores. The psychometric value of the KRT-R has been demonstrated on a sample of 3,246 children. A validity coefficient (correlation with school results) and reliability coefficient (Cronbach's α) of .50 and .92, respectively, were found for first grade.

The TTR (De Vos, 1992) is a numerical facility test consisting of 80 (first grade) or 200 (second grade) arithmetic number fact problems. In first grade, children receive a form with two subtests: one subtest with 40 addition problems (e.g., 2 + 3 = __) and one subtest with 40 subtraction problems (e.g., 8 – 3 = __). Children have to solve as many addition problems as possible in 1 minute. After that, they receive another minute to solve as many of the 40 subtraction problems as possible. For second grade, a form with five subtests is used. The first subtest requires addition (e.g., 2 + 3 = __), the second subtraction (e.g., 8 – 3 = __), the third multiplication (e.g., 5 × 9 =__), the fourth division (e.g., 15 ÷ 3 = __), and the fifth mixed exercises (addition, subtraction, multiplication, and division through each other). Children have to solve as many items as possible in 5 minutes; they can work 1 minute on each subtest. The TTR is a standardized test that is frequently used in Flemish education as a measure of early arithmetic acquisition. The total number of correct items were summed and converted to percentile scores. The psychometric value of the TTR has been demonstrated on a sample of 10,059 children in total (Ghesquière & Ruijssenaars, 1994). The Cronbach's alpha computed for the current study was .90. The Guttman split-half coefficient was .93; the Spearman–Brown coefficient was .95.

Intelligence. To have an estimation of the intellectual capacities of the children, a short version of the *Wechsler Intelligence Scale for Children–3rd edition* (WISC-III; Wechsler, 1991) was assessed. This is the most recent form in Flanders. The short version is based on four subtests and includes measures for both crystallized and fluid intelligence (Vocabulary, Similarities, Block Design, and Picture Arrangement; Grégoire, 2001). The mean intelligence of the children was 100.54 (*SD* = 13.37). No significant differences in intelligence were found between the AD, LA, TA, DF1, and DF2 groups (see Table 1).

Procedure

The children were recruited from 33 schools. The schools were randomly selected, with schools in the city and out of the city and representing all three types of schools in Belgium: Catholic schools, schools organized by the federal government, and schools organized by the cities or provinces (Desoete et al., 2004). Parents received a letter with the explanation of the research and submitted informed consent in order to participate every year.

Children were tested during school time in a separate and quiet room. Children were tested individually in kindergarten. The total duration of the individual testing was about 40 minutes. Tests were assessed in the same order and in the same period of the school year. In first and second grade, the children were assessed on arithmetic abilities (with the KRT-R) and on numerical facility (with the TTR). The TTR was presented first, and the KRT-R was presented second. The short version of the WISC-III was assessed individually in second grade.

The test leaders all received training in the assessment and interpretation of the tests. For every subtest, instructions and scoring rules were explained orally. To guarantee reliability of the assessment, each tester had to test one child and score the protocol in advance. This protocol was analyzed and corrected by the main researcher of the study. The test protocols were not included in the analyses of this study. All responses were entered on an item-by-item basis into SPSS. A second and third scorer independently reentered all protocols, with 99.9% agreement. After completion of the test procedure, all the parents of the children received individual feedback on the results of their children.

Results

> *Research Question 1:* How well do kindergarten (age 5–6) performances model the arithmetic abilities and numerical facility in Grade 1 (age 6–7) and Grade 2 (age 7–8)?

The research question on the proportion of variance in arithmetic skills that could be modeled by the performances in kindergarten is answered with a correlation among the kindergarten predictors and regression analyses. The correlation among the kindergarten variables are reported in Table 2.

In kindergarten, intelligence correlated significantly with almost all measures, except classification. The correlation between the Piagetian tasks in kindergarten was $r = .112$ ($p = .01$). Moreover, procedural counting and conceptual counting skills correlated significantly in kindergarten, $r = .296$ ($p < .0005$). In kindergarten also, magnitude comparison correlated significantly with procedural counting, $r = .156$ ($p = .001$); seriation, $r = .102$ ($p < .05$); and classification, $r = .093$ ($p < .05$).

To address the question on how well the kindergarten predictors (at age 5–6) model arithmetic achievement, regression analyses were conducted on the first- and second-grade outcomes (see Table 3).

First tested was whether the arithmetic abilities in Grade 1 could be modeled by classical Piagetian-type tasks and with other measures of procedural and conceptual counting knowledge and magnitude comparison tests in kindergarten. The linear combination of kindergarten predictors (at age 5–6) was significantly related to arithmetic reasoning assessed

Table 2. Correlations Among Kindergarten Predictors and Intelligence

	Intelligence	Conceptual Counting	Seriation	Classification	Magnitude Comparison
Procedural counting	.290***	.296***	.197***	.087	.156***
Conceptual counting	.219***	–	.231***	.185***	.076
Seriation	.241***	–	–	.112*	.102*
Classification	–.003	–	–	–	.093*
Magnitude comparison	.116*	–	–	–	.093*

*$p < .05$. ***$p < .0005$.

Table 3. Prediction of Arithmetic Abilities in Grades 1 and 2 From Preparative Abilities

	Arithmetic Abilities Grade 1 (age 6–7)				Numerical Facility Grade 1 (age 6–7)			
Kindergarten Abilities (age 5–6)	Unstandardized Coefficient	β	*t*	*p*	Unstandardized Coefficient	β	*t*	*p*
Constant	59.088		48.076	.000	9.097		35.558	.000
Procedural counting	4.871	.164	3.626	.000**	0.531	.090	1.884	.060
Conceptual counting	3.045	.100	2.178	.030	0.146	.024	0.499	.618
Seriation	6.125	.210	4.769	.000**	0.677	.117	2.513	.012
Classification	4.433	.157	3.609	.000**	0.909	.163	3.529	.000**
Magnitude comparison	3.958	.121	2.805	.005**	0.656	.101	2.217	.027
	Arithmetic Abilities Grade 2 (age 7–8)				**Fast Fact Retrieval Grade 2 (age 7–8)**			
Kindergarten Abilities (age 5 to 6)	Unstandardized Coefficient	β	*t*	*p*	Unstandardized Coefficient	β	*t*	*p*
Constant	59.088		48.076	.000	9.097		35.558	.000
Constant	62.391		49.184	.000	14.437		25.875	.000
Procedural counting	4.957	.168	3.548	.000**	1.735	.138	2.827	.005
Conceptual counting	3.637	.109	2.275	.023	0.812	.063	1.276	.203
Seriation	3.637	.125	2.723	.007**	1.296	.105	2.207	.028
Classification	2.554	.091	1.999	.046	–0.962	–.081	–1.717	.087
Magnitude comparison	1.879	.058	1.281	.201	–0.275	–.020	–0.428	.669

**$p \leq .008$ (after Bonferroni adjustment).

in Grade 1 (at age 6–7) with the KRT-R, $F(5, 458) = 20.423$, $p = .0005$, $R^2 = .184$, meaning that about 18% of the variance in arithmetic reasoning in Grade 1 could be modeled by assessing the performances of children 1 year earlier in kindergarten. In particular, the Piagetian seriation and classification tasks and the neo-Piagetian procedural counting and magnitude comparison tasks were beneficial as kindergarten predictors for arithmetic reasoning in Grade 1. The results also suggested that 8% of the variance in numerical facility, assessed in first grade (at age 6–7) with the TTR, could be modeled by assessing the preparatory arithmetic abilities in kindergarten (at age 5–6), $F(5, 458) = 8.066$, $p = .0005$, $R^2 = .082$. In particular, the Piagetian classification task was beneficial as a kindergarten predictor.

Further, whether the arithmetic abilities in Grade 2 could be modeled by kindergarten predictors was tested. The combination of kindergarten predictors (at age 5–6) was significantly related to arithmetic reasoning assessed in Grade 2 (at age 7–8) with the KRT-R, $F(5, 458) = 10.775$, $p = .0005$, $R^2 = .106$. In particular, the classical Piagetian-type seriation task and the neo-Piagetian procedural counting tasks were beneficial as kindergarten predictors for arithmetic reasoning in Grade 2. The kindergarten predictors (at age 5–6) were also significantly related to numerical facility assessed in Grade 2 (at age 7–8) with the TTR, $F(5, 458) = 4.408$, $p = .001$, $R^2 = .047$. Procedural counting was especially beneficial as a kindergarten predictor for numerical facility in Grade 2.

Table 4. Means, Standard Deviations (in parentheses), *F* Values, and Standardized Canonical Discriminant Function Coefficients of the Predictors for the Three Groups of Persistent Achievers

Kindergarten Predictors	AD	LA	TA	F (2, 340)	Standard Canonical Discriminant Function Coefficients
Procedural counting	–0.47 (0.92)	0.16 (0.96)	0.28 (0.92)	3.735*	.206
Conceptual counting	–0.38 (0.82)	0.24 (0.74)	0.24 (0.91)	2.785*	.120
Seriation	-0.58_b (1.10)	-0.52_b (1.08)	0.24_a (0.88)	11.920**	.543
Classification	–0.43 (0.98)	0.29 (1.05)	0.19 (0.96)	3.336*	.135
Magnitude comparison	-0.76_b (1.77)	-0.05_a (1.11)	0.19_a (0.52)	15.395**	.690

Note: AD = persistent arithmetic disabilities group; LA = persistent low-achieving group; TA = persistent typically achieving group. Children in TA group (subscript *a*) were better than those in the AD group (subscript *b*) on seriation and magnitude comparison tasks. Children in the TA group were better than those in the LA group on seriation tasks (subscript *ab*) but not on magnitude comparison tasks (subscript *aa*). Children in the LA group were better than those in the AD group on magnitude comparison tasks (subscript *ab*) but not on seriation tasks (subscript *bb*).
$^*p < .05$. $^{**}p \leq .008$ (after Bonferroni adjustment).

Research Question 2: Is it possible to find group differences between persistent arithmetic ability groups (AD, LA, TA)?

The research question of whether it was possible to find differences between groups of children with persistent arithmetic performances based on potential severity, without confounding group differences in intelligence, is addressed with a multivariate analysis of covariance (MANCOVA). Using the Bonferroni method, each ANOVA was tested at the .008 level, correcting for experiment-wise error rate.

The MANCOVA was conducted on intelligence as the covariate; group (AD, LA, TA) as independent variables; and procedural counting knowledge, conceptual counting knowledge, seriation, classification, and magnitude comparison (at age 5–6) as dependent variables. The MANCOVA was significant on the multivariate level for intelligence, $F(5, 336) = 12.921$, $p = .0005$, and also for the group (AD, LA, TA), $F(10, 672) = 6.265$, $p = .0005$. The means and standard deviations of the dependent variables for the three groups are shown in Table 4.

On the univariate level, post hoc analyses revealed that the TA group (in Table 4, subscript *a* index) performed significantly better than the AD group (subscript *b* index) on seriation and magnitude comparison tasks (at age 5–6) and significantly better than the LA group (subscript *b* index) on seriation but not on magnitude comparison tasks (subscript *a* index). Children in the LA group (subscript *b* index) did not differ significantly from those in the AD group (subscript *b* index) on seriation. However, children in the LA group (subscript *a* index) did significantly better than those in the AD group (subscript *b* index) on magnitude comparison tasks.

Research Question 3: Is it possible to predict group membership within persistent arithmetic ability groups?

Our next research question was whether it was possible to predict persistent arithmetic disabilities in Grade 2 (at age 7–8) based on the kindergarten predictors assessed 2 years earlier. This research question was answered with four analyses. First, the research question was addressed by conducting a discriminant analyses on kindergarten tests to investigate the overall accurateness of the predicted classifications in the AD, LA, or TA groups (at age 7–8). Second, the contribution of each kindergarten predictor was reported uniquely. Third, with receiver-operating characteristic (ROC) curves, group membership (AD vs. non-AD) was predicted and the sensitivity and specificity of the predictors was described. Finally, to obtain an easier clinical and sample-independent interpretation, it was investigated if the kindergarten clinical cutoff scores (at age 5–6), based on the stratified normative sample of the TEDI-MATH, are consistent with the sample-dependent analyses with *z* scores.

First, Fisher's linear discriminant function was used to investigate the accurateness of the predicted classifications in the AD, LA, and TA groups. The overall Wilks's Lambda was significant, $\Lambda = .831$, $\chi^2(10, N = 357) = 65.263$, $p = .0005$, indicating that overall the kindergarten predictors differentiated among the AD, LA, and TA group. In Table 4, the standardized weights of the predictors are presented. Based on these coefficients, magnitude comparison and seriation demonstrated the strongest relationships with the general arithmetic achievement of the children. The means on the discriminant function were consistent with this interpretation. The typically achieving children did better on the preparatory arithmetic abilities. Based on the scores for these kindergarten predictors, 88.0% were classified correctly into the AD, LA, or TA group in Grades 1 and 2, whereas 88.0% of the cross-validated grouped cases were classified correctly. However, only 18.8% of the children with arithmetic disabilities, no children who are low achieving, and 99.0% of the typically achieving children were classified correctly. Table 5 gives an

Table 5. Percentages of Observed and Predicted Group Membership of the Persistent Achievers Based on the Discriminant Function

Observed Group Membership	Predicted Group Membership		
	AD	LA	TA
AD	18.8	0	81.3
LA	11.1	0	88.9
TA	1.0	0	99.0

Note: AD = persistent arithmetic disabilities group; LA = persistent low-achieving group; TA = persistent typically achieving group.

Table 6. Receiver Operating Characteristic Curve

	Area Under the Curve	Standard Error	Confidence Interval	*p*
Procedural counting	.721	.053	.617 – .824	.003
Conceptual counting	.717	.061	.597 – .837	.003
Seriation	.707	.075	.561 – .853	.005
Classification	.645	.074	.501 – .789	.051
Magnitude comparison	.725	.071	.586 – .865	.002

overview of the classification results based on this discriminant function.

To take into account chance agreement, a kappa coefficient was computed and obtained a value of .17, indicating a weak prediction. To see how well each predictor uniquely predicts group membership, the contribution of each predictor is uniquely reported.

The overall Wilks's Lambda for the Piagetian tasks was significant, namely, $\Lambda = .929$, $\chi^2(2, N = 358) = 26.256$, $p = .0005$, for seriation (with 100% of the typically achieving children but none of children who are low achieving or those with arithmetic disabilities classified correctly) and $\Lambda = .982$, $\chi^2(2, N = 358) = 6.577$, $p = .037$, for classification, respectively (with 100% of the typically achieving children but none of children who are low achieving or those with arithmetic disabilities classified correctly), indicating that overall the Piagetian kindergarten predictors differentiated among the AD, LA, and TA groups.

The overall Wilks's lambda for the neo-Piagetian counting tasks and the magnitude comparison tasks were significant, namely, $\Lambda = .971$, $\chi^2(2, N = 357) = 10.365$, $p = .006$, for procedural counting knowledge (with 100% of the typically achieving children but none of the children who are low achieving or those with arithmetic disabilities classified correctly), $\Lambda = .981$, $\chi^2(2, N = 357) = 6.901$, $p = .032$, for conceptual counting knowledge (with 100% of the typically achieving children but none of the children who are low achieving or those with arithmetic disabilities classified correctly), $\Lambda = .919$, $\chi^2(2, N = 357) = 30.119$, $p = .0005$, for number comparison tasks (with 99% of the typically achieving children, none of the children who are low achieving, and 18.8% of those with arithmetic disabilities classified correctly), indicating that overall the neo-Piagetian kindergarten predictors differentiated among the AD, LA, and TA groups.

In addition, Table 6 gives an overview of the ROC curves based on the standardized scores as coordinates to determine the sensitivity and specificity to identify children with arithmetic disabilities versus children without arithmetic disabilities in elementary school. Magnitude comparison was the most sensitive task, whereas procedural knowledge had the highest specificity as a kindergarten predictor.

Finally, to obtain an easier clinical and sample-independent interpretation, it was investigated if the use of clinical cutoff scores in kindergarten (at age 5–6) were consistent with the previous analyses on *z* scores. The percentage of true-positive children with arithmetic disabilities (at age 7–8) correctly detected in kindergarten (at age 5–6) by the combination of the seriation, classification, procedural counting, conceptual counting, and magnitude comparison predictors was 87.50%. There were 18.25% false positives, or children with arithmetic disabilities not failing at age 5 to 6 on the kindergarten measures but developing arithmetic disabilities (at age 7–8) in elementary school. In our sample, none of the children with arithmetic disabilities in elementary school failed on the Piagetian seriation or classification tasks as preschoolers. There were 12.50% of the children with arithmetic disabilities in elementary school with clinical scores on neo-Piagetian procedural counting tasks assessed in kindergarten. In addition, conceptual counting assessed in kindergarten detected 31.25% of the children with arithmetic disabilities in elementary school. Finally 43.75% of the children with arithmetic disabilities in elementary school already had clinical scores on magnitude comparison tasks in kindergarten.

In addition, the clinical specificity was 89.40% in the TA group. In our data set, 0.15% of the typically achieving children scored below the clinical cutoff on procedural counting tasks in preschool, and 5.95% scored below this cutoff on conceptual counting tasks. No false negatives were found on seriation, classification, and magnitude comparison tasks in kindergarten.

Research Question 4: Do children with persistent or inconsistent arithmetic abilities differ in kindergarten skills?

The research question of whether it is possible to find differences between children with persistent or inconsistent performances without confounding group differences in

Table 7. Means, Standard Deviations (in parentheses), and *F* Values for the Two Groups of Inconsistent Achievers (DF1, DF2) Compared With Persistent Achievers (AD, TA)

	AD	DF1	DF2	TA	*F* (3, 415)
Procedural counting	–0.47 (0.92)	0.38 (0.96)	0.24 (0.89)	0.28 (0.92)	3.265*
Conceptual counting	–0.38 (0.82)	0.34 (0.93)	0.39 (0.87)	0.24 (0.91)	2.166*
Seriation	-0.58_b (1.10)	-0.14_b (1.02)	0.19_a (0.88)	0.24_a (0.88)	4.852***
Classification	-0.43_b (0.98)	0.11 (1.01)	-0.48_b (0.89)	0.19_a (0.96)	6.887***
Magnitude comparison	-0.76_c (1.77)	-0.17_b (1.22)	–0.15 (1.17)	0.19_a (0.52)	9.790***

Note: AD = persistent arithmetic disabilities group; DF1 = inconsistent arithmetic disability group; DF2 = inconsistent low-achieving group; TA = persistent typically achieving group. Children in the AD group (subscript *b*) did not differ significantly from children in the DF1 group (subscript *b*) seriation tasks, but they had worse magnitude comparison skills (subscript *c*). Children in the TA group (subscript *a*) did not differ significantly from those in DF2 (subscript *a*) on seriation and magnitude comparison skills. Children in the TA group (subscript *a*) were better than those in DF2 (subscript *b*) on classification tasks.
*$p < .05$. ***$p \leq .0005$.

intelligence was addressed with a MANCOVA. We were especially interested in the differences between the children with persistent arithmetic disabilities (AD group) and those with inconsistent arithmetic disabilities (DF1 group). In addition, we were interested in the differences between the persistent typical achievers (TA group) and the inconsistent low achievers (DF2 group).

From all participants, 64.23% children appeared to have stable or persistent arithmetic abilities, whereas 35.77% children had inconsistent abilities (DF1 and DF2) with fluctuating arithmetic test scores.

A MANCOVA was conducted to investigate the differences between the AD, TA, DF1, and DF2 groups on five dependent variables: procedural counting knowledge, conceptual counting knowledge, seriation, classification, and magnitude comparison (assessed in kindergarten), with intellectual abilities as the covariate. The MANCOVA was significant on the multivariate level for the covariate, $F(5, 411) = 12.506$, $p = .0005$, but also for the group, $F(15, 1{,}134.991) = 4.341$, $p = .0005$. The means and standard deviations of the dependent variables for the two instable groups are shown in Table 7.

Post hoc analyses, using the Bonferroni method, revealed that the children with inconsistent arithmetic disabilities (DF1) performed significantly better than the children with persistent arithmetic disabilities (AD) on neo-Piagetian magnitude comparison tasks (in Table 7, subscript *a* index vs. subscript *b* index). The children with persistent typical achievement (TA) were significantly better than the children with inconsistent low achievement (DF2) on Piagetian classification tasks (subscript *a* index vs. subscript *b* index).

Discussion

Several cognitive antecedents have been suggested as factors that play a role in the development of initial arithmetic performance and eventually as early markers for arithmetic disabilities. In 1941, Piaget postulated that logical abilities are conditional for the development of arithmetic (Piaget & Szeminska, 1941). However, until now, the debate on the value of seriation and classification as Piagetian abilities remains unsolved (e.g., Grégoire, 2005; Lourenço & Machado, 1996; Nunes et al., 2007; Stock et al., 2007, in press). Besides these Piagetian logical abilities, neo-Piagetian researchers focused on the importance of procedural and conceptual counting knowledge in the development of arithmetic performance (e.g., Aunola et al., 2004). Finally, because Landerl et al. (2004) suggested that the core problem of arithmetic disabilities might be a deficit in number sense, it might be interesting to explore if magnitude comparison can be used as an early marker for arithmetic disabilities (e.g., Durand et al., 2005). Because there is not yet a consensus regarding which of these types of kindergarten predictors are uniquely associated with early responses to formal arithmetic instruction in first and second grade, this study used a combination of Piagetian seriation and classification tasks with other measures of conceptual and procedural counting knowledge as well as a magnitude comparison task. Based on the possible group differences in intelligence among children, which might present a confound in the assessment of arithmetic performance, in this study IQ was added as covariate. The combination of these measures using a large sample of children makes this study relatively rare in this type of research.

Children were grouped based on their arithmetic ability into one of five groups: persistent arithmetic disabilities (AD), persistent low achievement (LA), persistent typical achievement (TA), inconsistent arithmetic disabilities (DF1), and inconsistent low achievement (DF2). In line with Murphy et al. (2007), the persistent AD and LA groups were separated based on potential severity. Children in the AD group corresponded to the restrictive selection criteria of an arithmetic disability, scoring successively at or below the 10th percentile on arithmetic tests, whereas children in the LA group were low achieving in arithmetic scoring successively between the 11th and 25th percentile. Children in the TA group had age-appropriate achievement in Grades 1 and 2, scoring above the 25th percentile on arithmetic tests. Moreover, in line with Fletcher et al. (2005) and Murphy et al. (2007), the present study separated persistent and inconsistent achievers, addressing the status model that attempts to identify children based on an assessment at one single testing point (DF1, DF2) and the fluctuating model or the results of children classified based on their arithmetic achievement scores for at least 2 years (AD, TA). Children classified into the DF1 group had severe but nonpersistent arithmetic difficulties, performing below or at the 10th percentile in one grade and above the 25th percentile in the other grade. The children classified into the DF2 group had mild but nonpersistent arithmetic difficulties, scoring between the 11th and 25th percentile in one grade and above the 25th percentile in the other grade. The children in the DF1 and DF2 groups may be excluded from prior studies that use persistence as a basis for inclusion in arithmetic ability groups. In short, we explored if the kindergarten characteristics of children varied as a function of the cutoff (AD vs. LA) and persistence (AD vs. DF1) as a basis for inclusion in arithmetic ability groups.

This study revealed that nearly one fifth of the variance in arithmetic reasoning in Grade 1 (age 6–7) could be explained by assessing the performances of children in kindergarten (age 5–6) 2 years earlier. In particular, the Piagetian seriation and classification tasks and the neo-Piagetian procedural counting and magnitude comparison tasks were beneficial as kindergarten (age 5–6) predictors. Nearly one tenth of the variance in numerical facility in first grade (age 6–7) could be modeled by assessing the kindergarten performances. The Piagetian classification task in particular was a significant predictor.

In addition, one tenth of the variance in arithmetic abilities and about one twentieth of the numerical facility in Grade 2 (age 7–8) could modeled by kindergarten (age 5–6) performances 2 years earlier. In particular, the classical Piagetian-type seriation tasks and the neo-Piagetian procedural counting tasks were beneficial to model the variance in arithmetic reasoning, whereas the neo-Piagetian procedural counting task was beneficial as a kindergarten predictor for the variance in numerical facility.

These findings stress the need for a model of the development of arithmetic abilities that includes seriation and classification as Piagetian logical abilities but also procedural counting knowledge and magnitude comparison as neo-Piagetian insights (age 5–6). This model could serve as a framework for a better understanding of the development of arithmetic abilities in Grades 1 and 2. The longer the follow-up period, the weaker the prediction from kindergarten (age 5–6) performances, but the assessment of preparatory arithmetic abilities in kindergarten seemed still to have value for the prediction of arithmetic abilities even 2 years later. However, the studies in Grades 1 and 2 have not consistently pointed out one and the same predictor. It makes it clear that it is not good practice to look for a single deficient arithmetic ability. These conclusions indicate that it is important to build models that include the several markers for arithmetic development and then investigate the interactions between those components.

Moreover, in line with the studies of Geary et al. (2007) and Murphy et al. (2007), the present study highlighted differences in kindergarten skills based on the definition of arithmetic disabilities. Concerning performances on the Piagetian seriation tasks in kindergarten (age 5–6), no significant differences were found between the children in the AD group and those in the LA group, but both groups performed significantly worse on seriation tasks than did typically achieving children in kindergarten. However, there were significant differences between the AD and LA groups on the magnitude comparison task in kindergarten, with children with arithmetic disabilities having less developed preparatory arithmetic abilities than the children who are low achieving. The significant differences in the kindergarten performances between children with arithmetic disabilities and those who are low achieving on the magnitude comparison task strengthen the idea that this might be one of the core deficits in children with arithmetic disabilities (Butterworth, 2005; Gersten et al., 2005; Holloway & Ansari, 2009; Landerl et al., 2004). This supports the fact that the results of children who are low achieving cannot automatically be applied to children with arithmetic disabilities, implying major consequences for the selection of samples in future research. It is hypothesized that children with arithmetic disabilities show qualitatively different skills than children who are low achieving in arithmetic, and this hypothesis is confirmed by the recent findings of Mazzocco et al. (2008) in older children and by studies of Geary et al. (2007). They also found that children with arithmetic disabilities showed qualitatively different profiles in fact-retrieval performances when compared to typically achieving children, whereas the differences between children who are low achieving and those who are typically achieving were of a quantitative turn. Because the criteria used to define children with arithmetic disabilities in the current study approach criteria used in clinical practice, this also implicates that clinicians have to be careful with conclusions of scientific studies that use a more lenient criterion.

The third purpose of this study was to classify children as persistent typical achieving, as persistent low achieving, or as with persistent arithmetic disabilities based on the kindergarten preparatory abilities. The study revealed that seven out of eight children in Grade 2 (at age 7–8) could be classified correctly into the arithmetic disabilities, low-achieving, or typically achieving group based on their kindergarten preparatory arithmetic abilities assessed 2 years earlier (at age 5–6). However, fewer than one fifth of the children with arithmetic disabilities, no children who are low achieving, but nearly all typically achieving children could be classified correctly. All kindergarten tasks contributed to the general prediction, but only the number comparison tasks contributed to a correct classification of children with arithmetic disabilities in Grade 2 (age 7–8). These results showed that it was easier to screen the children who are not at risk than to detect the at-risk children based on their kindergarten abilities. The ROC curves revealed that magnitude comparison was the most sensitive kindergarten task, whereas procedural knowledge had the highest specificity as a kindergarten predictor. Moreover, based on clinical cutoff scores, seven out of eight children with arithmetic disabilities (at age 7–8) could already be correctly detected in kindergarten (at age 5–6). One out of eight children with arithmetic disabilities failed on neo-Piagetian procedural counting tasks, and the conceptual counting tasks detected about one out of three children with arithmetic disabilities in Grade 2 already in kindergarten (age 5–6). Finally, more than two fifth of the children with arithmetic disabilities (age 7–8) already had clinical scores on magnitude comparison tasks in kindergarten (age 5–6). In addition, the clinical specificity of the five kindergarten predictors was about nine tenth. No false negatives were found on magnitude comparison as kindergarten task. These results underline that it is important to include magnitude comparison measures but also procedural and conceptual counting tasks in assessment batteries that aim to prospectively detect kindergartners (age 5–6) who are at risk for arithmetic disabilities in the first 2 years of elementary schools.

The fourth purpose of this study was to look for differences in kindergarten performances (age 5–6) between children with persistent or inconsistent arithmetic abilities. In line with the status model, our data revealed that about two thirds of the children had persistent arithmetic achievement (AD, LA, TA). However, in line with the fluctuation model (Fletcher et al., 2005), there was a big amount of instability in the identification of class members because test scores fluctuated with repeated testing in one third of the children (DF1, DF2). Similar fluctuations were described by Fletcher et al. Moreover, the group with inconsistent arithmetic disabilities differed significantly on magnitude comparison tasks but not on seriation tasks in kindergarten (age 5–6) from the group with persistent arithmetic disabilities. In addition, the children with inconsistent low achievement differed significantly from the persistent typical achievers on classification but not on seriation tasks in kindergarten. These results showed that different conclusions could be drawn when using children with inconsistent disabilities and those with persistent arithmetic disabilities together in one group. The use of children with inconsistent disabilities and children with arithmetic disabilities together in one sample may conflate children with severe arithmetic disabilities and children with fluctuating arithmetic performances. Moreover, the use of children with inconsistent disabilities challenges intervention studies because the spontaneous fluctuations in arithmetic performances might mask or overemphasize differences between children with arithmetic disabilities and those who are average achievers. Also, the use of children with inconsistent low achievement in the recruitment of clinical control samples might be a problem.

The results of the current study have to be interpreted with care because some other possible powerful predictors for arithmetic disabilities were not taken into account. Geary, Bailey, and Hoard (in press) assessed the speed and accuracy with which children can identify and process quantities. Based on children's performance in first grade, they were able to detect two out of three children identified as having arithmetic disabilities at the end of third grade. Perhaps the inclusion of the speed factor was responsible for the better classification results obtained compared to our ROC analyses. In addition, several authors stressed the importance of executive functions (e.g., Mazzocco & Kover, 2007; Van der Sluis, de Jong, & van der Leij, 2007), working memory (e.g., Bull, Espy, & Wiebe, 2008; Geary & Widaman, 1992; Passolunghi, Mammarella, & Altoe, 2008; Passolunghi & Siegel, 2004; Ricken & Fritz, 2006), and attention (Marzocchi, Lucangeli, De Meo, Fini, & Cornoldi, 2002) in the development of arithmetic (dis)abilities. It even might be so that working memory is related to some of the indicators proposed in the study as well. Future research is needed on speed and accuracy, executive function and working memory in the differentiation of children with arithmetic disabilities, those who are low achieving, and those with inconsistent arithmetic disabilities. Finally, context variables such as home and school environment, learning packages, and parental involvement (e.g., Reusser, 2000) should be included in order to obtain a complete overview of the arithmetic development of these children. These limitations indicate that only a part of the picture was investigated, so the results of the study have to be interpreted with care. Yet, the study included an in-depth assessment of the arithmetic performances of the children during 3 consecutive years. Because few large-scale studies have been done (Porter, 1998), the size of the group of children that was assessed in this study strengthens the generalizability of the results. Finally, the use of lenient as well as restrictive criteria and the inclusion of an assessment of the intellectual capacities of the children further empower this study.

However important implications and challenges for future research can be drawn. First of all, researchers should be careful with selection criteria when composing research samples. Restrictive cutoff criteria (scores at or below the 10th percentile) and the implementation of the resistance-to-instruction criterion (clinical scores in at least 2 consecutive years, although task-specific instruction was given between both measuring points) seem indicated. Second, we can only detect kindergarten predictors of arithmetic performance in

Grades 1 and 2 with a hybrid model combining Piagetian-type tests, neo-Piagetian counting tasks, and number comparison screening in kindergarten. We propose to integrate seriation and classification in a model that also includes procedural and conceptual counting knowledge and magnitude comparison. It is recommended that we should not try to assess one kindergarten predictor but rather to look for a set of markers when we aim to model variance in later arithmetic abilities. Moreover, researchers should be aware that a large part of the variance in arithmetic abilities cannot yet be explained. Additional research is needed on larger context variables and on other underlying factors as well as on resistance to instruction to build such a model. The third and perhaps most important educational challenge for the future is to accommodate the need for intervention studies (Gersten et al., 2005). Early intervention can remediate difficulties and alter children's arithmetic development (Fuchs & Fuchs, 2001), but if we really want to screen children on their early arithmetic abilities in order to prevent the development of arithmetic disabilities, it will be important to focus on assessments that are directly related to instruction. Only response-to-intervention (RTI) studies can sufficiently serve that goal (Fletcher, Coulter, Reschly, & Vaught, 2004).

In conclusion, some of the variance in arithmetic could be explained in the 3-year longitudinal study by the kindergarten performances on Piagetian-type tasks as well as on neo-Piagetian procedural counting and magnitude comparison tasks. Moreover, significant differences in the performances on magnitude comparison can be found between children with persistent arithmetic disabilities and those who are persistent low achieving, but also between children with persistent arithmetic disabilities and those with inconsistent arithmetic disabilities. Furthermore, based on the clinical cutoff scores on the number comparison, procedural counting, and conceptual counting tasks in kindergarten (at age 5–6), seven out of eight kindergartners at risk for persistent arithmetic disabilities in Grades 1 and 2 could be detected.

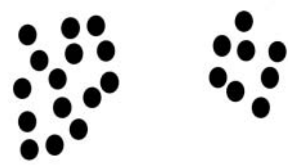
Appendix

Subtests and Examples of Test Items of the Test for the Diagnosis of Mathematical Competences

Subtest	Content and Example of Item
1. Procedural knowledge (13 items, max. 14 points)	• Counting as far as possible (without help = 2 points; with starting help = 1 point) • Counting forward to an upper bound ("*up to 9*") • Counting forward to an upper bound ("*up to 6*") • Counting forward from a lower bound ("*from 3*") • Counting forward from a lower bound ("*from 7*") • Counting forward from a lower bound to an upper bound ("*from 5 up to 9*") • Counting forward from a lower bound to an upper bound ("*from 4 up to 8*") • Counting forward ("*5 steps starting at 8*") • Counting forward ("*6 steps starting at 9*") • Count backward ("*from 7*") • Count backward ("*from 15*") • Count by step (*by 2*) • Count by step (*by 10*)
2. Conceptual knowledge (7 items, max. 13 points)	• Counting linear pattern of items - max. 3 points ("*How many rabbits are there? How many rabbits are there in total?*" and "*How many rabbits are there if you start counting with this one. Why?*") • Counting linear pattern of items - max. 3 points ("*How many lions are there? How many lions are there in total?*" and "*How many lions have I hidden. Why?*") • Counting random pattern of items - max. 2 points ("*How many turtles are there? How many turtles are there in total*?") • Counting random pattern of items - max. 2 points ("*How many sharks are there? How many sharks are there in total?*") • Counting a heterogeneous set of items - max. 1 point ("*How many animals are there in total?*") • Understanding of the cardinal - max. 1 point ("*Can you put as much counters as there are on this paper?*") • Understanding of the cardinal - max. 1 point ("*How many hats do I have in my hand, when all the snowmen had a hat on this picture?*")

(continued)

Appendix (continued)

Subtest	Content and Example of Item
3. Logical operations on numbers (6 items, max. 6 points)	• Seriation - max. 3 points (“*Sort the cards from the one with fewer trees to the one with the most trees. Forget this card*” and “*Can you put this card in the correct order?*” and “*I give you carts with numbers now. Do the same as with the trees. Start with the cart with smallest number and go on with the other carts*”) • Classification - max. 3 points (“*Make groups with the cards that go together. Can you put them together in another way?*” and “*Make groups with these cards that go together*”)
4. Estimation of size (6 items, 6 points)	Comparison of dot sets (subitising): in preschool and grade I  *Where do you have most dots? Here or here? Show me.* *1 dot versus 3 dots* *3 dots versus 2 dots* *4 dots versus 6 dots* *7 dots versus 2 dots* *7 dots versus 12 dots* *15 dots versus 8 dots (see example)*

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