Language in the prediction of arithmetics in kindergarten and grade 1

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Abstract

A large body of evidence supports the central influence of counting in the development of adequate arithmetic skills. Moreover a substantial amount of children with mathematical learning disabilities in elementary school can be correctly diagnosed in kindergarten by the combination of counting and magnitude estimation tasks. The present study expands previous findings, by adding language and logical thinking as predictors for arithmetic skills in kindergarten and grade 1.

A sample of 63 children was tested in kindergarten on counting, logical thinking, estimation (number line estimation, number naming and number comparison), language and arithmetic skills. These children were tested again on arithmetic in grade 1. Results reveal that expressive language explains 24% of the variance in arithmetic skills among kindergarteners controlling for number naming and procedural counting knowledge as predictors. Moreover, language still predicts grade 1 arithmetic. In addition, our findings suggest that number naming and number comparison are better predictors than number line estimation of arithmetic skills in kindergarten.

Highlights

- Procedural and conceptual counting knowledge explain about 25% of the variance in arithmetic skills among kindergarteners
- Number comparison and number naming skills explain about 39% of the variance in arithmetic skills among kindergarteners
- Expressive language explains 24% of the variance in arithmetic skills among kindergarteners, controlling for counting, estimation and logical thinking.
- Language explains about 5% of the variance in grade 1 arithmetic, controlling for kindergarten arithmetic, counting and estimation skills.

1. Introduction

There has been extensive research on counting (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Fuson, 1988; Hannula, Räsänen, & Lehtinen, 2007; Le Corre, Van de Walle, Brannon, & Carey, 2006; Stock, Desoete, & Roeyers, 2009) predicting arithmetic in the primary grades. Moreover, 87% of the children with mathematical learning disabilities in grade 2 (at age 7 to 8) can be correctly diagnosed in kindergarten by a combination of counting and magnitude estimation tasks (Stock, Desoete, & Roeyers, 2010). In addition to numerical abilities, the value of including logical thinking abilities (e.g., Nunes et al., 2006; Stock et al., 2009) and language as predictors for arithmetic has been stressed (e.g., Purpura, Hume, Sims, & Lonigan, 2011; Vukovic & Lesaux, 2013).

Surprisingly few studies have been conducted to explore the combined effect of these predictors on arithmetic in kindergarten and the primary grades. This study addresses this gap by investigating language in addition to counting, logical thinking and estimation as predictors of early arithmetic skills in young children.

1.1. Counting in kindergarten and early arithmetic

Before children start formal schooling, learning about numbers is largely focused on counting (LeFevre et al., 2006). Aunola et al. (2004) revealed, in a longitudinal study in which 194 Finnish children were followed up from kindergarten till grade 2, that counting knowledge was the best predictor not only of the initial arithmetic performance level, but also of the subsequent growth in arithmetical performance. Stock and colleagues (2010) confirmed the value of counting in 471 Belgian children.

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 children's ability to perform a counting task, for example, a child succeeds determining that there are five objects in an array (LeFevre et al., 2006). 'Conceptual counting knowledge' reflects a child's understanding of the essential counting principles: the stable order principle, the one-one-correspondence principle and the cardinality principle (LeFevre et al., 2006).

There isn't much research examining the independent effect of procedural and conceptual knowledge of counting on arithmetic skills among kindergarten and first grade students. This study addresses that gap.

1.2. Number estimation in kindergarten and early arithmetic

Estimation is an important skill both in the classroom and in everyday life (Siegler & Booth, 2004). It was documented to be correlated with arithmetic performance (Ashcraft & More, 2012; Geary, 2011; Halberda, Mazzocco, & Feigenson, 2008; Price, Palmer, Battista, & Ansari, 2012). Moreover, deficits in estimation were found in elementary school children diagnosed with mathematical learning disabilities (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Landerl, Bevan, & Butterwordt, 2004; Piazza et al., 2010; Stock & Desoete, 2009; Stock et al., 2010).

There are divergent paradigms used to assess estimation skills in kindergarten. A lot of researchers focus on the positioning or estimation of numerals on a number line (e.g. Berteletti et al., 2010; Siegler & Booth, 2004). However, there is some discussion on this Number Line Estimation (NLE) paradigm (e.g. Cohen & Blanc-Goldhammer, 2011; Defever, Sasanguie, Gebuis, & Reynvoet, 2011; Van Opstal & Verguts, 2011) and its relationship with proficient arithmetic. Therefore, in some studies other paradigms have been used, making study outcome difficult to compare. Hannula et al. (2007) and Fischer et al. (2008) used number naming or enumeration tasks to assess the estimation skills in young children. In addition, Halberda and Feigenson (2008) and Inglis, Attridge, Batchelor and Gilmore. (2011) used number comparison tasks where children have to judge on which side of the screen they saw most dots to get a picture of the estimation skills in young children.

This study combines the three tasks for estimation since these tasks may or may not represent the same construct in young children.

1.3. Logical thinking skills in kindergarten and early arithmetic

Piaget (1965) argued that the full development of arithmetic skills and number comprehension is only possible when children master logical thinking skills, such as the seriation and classification skills. 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. These logical thinking kills have been suggested as key precursors for arithmetical achievement (Nunes et al., 2006).

Although Neo-Piagetian researchers questioned the causality of seriation and classification for understanding number (e.g., Grégoire, 2005; Lourenço & Machado, 1996), even after controlling for differences in working memory, logical thinking skills in six year-old children remain a strong predictor for arithmetic abilities 16 months later (Nunes et al., 2006).

Studies exploring on the combined effects of logical thinking and other predictors of early arithmetic are scarce. This study addresses this gap in the literature.

1.4. Language in kindergarten and early arithmetic

Recently the value of including language as measure has been stressed in the prediction of numeracy development (Heim, Amunts, Drai, Eickhoff, Hautvast, & Grodzinksy, 2012; Purpura et al., 2011; Romano, Babchishin, Pagani, & Kohen, 2010; Sarnecka et al., 2007; Wiese, 2003). Oral language skills include receptive language, expressive language and the understanding of grammatical rules and the structure of language (Purpura et. al, 2011; Storch & Whitehurst, 2002). Receptive language refers to the understanding of words and word classes (e.g., understanding words as ‘more’, ‘big’, ‘three’). Expressive language refers to using words or word classes to identify an object, person or activity. The understanding of grammatical rules and the structure of language refers to the use of sentences.

Whether or not language helps children in kindergarten to solve mathematical problems, remains a point of discussion. Some studies (Barner, Chow, & Yang, 2009; Negen & Sarnecka, 2012) reveal that general measures of language development predict number-word knowledge, although other studies (e.g., Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003) did not support such a link. In addition, Cowan and Renton (1996) indicated that number words facilitate mathematical reasoning, whereas Levine, Jordan and Huttenlocher (1992) and Canobi and Bethune (2008) demonstrated that children in kindergarten were better problem solvers in the absence of number words.

This study is aiming to add some nuance to the literature by combining language with other predictors, such as counting, logical thinking and number estimation skills and by looking at receptive versus expressive language and at language content and structure in kindergarten.

1.5. The current study

Although there is plenty of evidence that kindergarten skills are important predictors of later arithmetic achievement, there is little research simultaneously tapping the relationship between counting, number estimation, logical thinking, and language in kindergarten and grade 1 empirically. Thus, two major hypotheses were examined:

1. Language, counting, estimation and logical thinking will predict kindergarten arithmetic when controlling for the others.
2. Language, counting, estimation and logical thinking will predict grade 1 arithmetic when controlling for arithmetic skills in kindergarten.

2. Method

2.1. Participants

In this study 63 children (30 girls) from five kindergarten schools in Zele (Belgium) and surrounding areas were tested at two measurement points. Parental consent was obtained for each child. Most children came from working- and middle-class socio-econonomic backgrounds. Dutch was the only language spoken at a home.

The first assessment was conducted in the last year of kindergarten (T1). The children's average age was 68.21months (*SD* = 4.19). The mean intelligence of the sample was TIQ = 98.35 (*SD*=13.88), VIQ = 100.71 (*SD*=13.00), PIQ = 97.57 (*SD*=12.77).

2.2. Measure

2.2.1. Counting knowledge

Procedural knowledge of counting was assessed with subtest 1 of the Tedi-Math (Grégoire et al., 2004) at T1, 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'), counting forward with an upper and lower bound (e.g., 'count form 5 up to 9') as indication for the procedural counting knowledge. The internal consistency of this task was good (Cronbach's Alpha = .73).

Conceptual knowledge of counting was assessed with subtest 2 of the Tedi-Math (Grégoire et al., 2004) at T1. Children were 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. The internal consistency of this task was good (Cronbach's Alpha = .85).

2.2.2. *Number estimation skills*

Number estimation was assessed with a Number Line Estimation (NLE) test, a number comparison and a number naming task at T1.

In the **NLE-task**, children were asked to put a single mark on number line to indicate the location of a number. In line with Berteletti , Lucangeli, Piazza, Dehaene, and Zorzi (2010) and Booth and Siegler (2006) an 0-100 interval was used. The task was computerized and included three exercise trials and 27 test trials. Stimuli were presented in three different formats, as Arabic numerals (e.g. anchors 0 and 100, target number 25), spoken number words (e.g. anchors zero and hundred, target number twenty five), and dot patterns (e.g. anchors of zero dots and hundred dots, target number twenty five dots). The dot patterns were controlled for perceptual variables using the procedure of Dehaene, Izard and Piazza (2005), meaning that on half of the trials dot size was held constant, and on the other half, the size of the total occupied area of the dots was held constant. The percentage absolute error (PAE) was calculated for each child as a measure of children's estimation accuracy following formula by Siegler and Booth (2004). For example, if a child was asked to estimate 25 on a 0-100 number line and placed the mark at the point on the line corresponding to 40, the PAE would be (40-25) / 100 or 15%.

In the **number naming task** (a quantity estimation and naming task) participants were instructed to say aloud the number of black squares (varying from one to nine) on a white background they saw on the monitor. The individual area, total area, and density of the squares varied to ensure that participants could not use non-numerical cues to make a correct decision (see Dehaene et al., 2005; Holloway & Ansari, 2009; Maloney, Risko, Ansari, & Fugelsang, 2010). Responses were collected using a microphone headset. Each trial began with a fixation point presented for 500 ms. Before the start of the task, 15 practice items were administered to ensure that the participants understood the task instructions. The presentation time was 120 msec (as used in the study of Hannula et al. (2007) and Fischer et al. (2008) and the child had to react within 5 seconds after the presentation. The test session consisted of 72 samples with a presentation time of 1200 msec. The reaction time was reduced to 500 msec. Reaction time and the number of correct responses was measured.

In the N**umber comparison task** (another quantity estimation and comparison task), in line with Halberda and Feigenson (2008) and Inglis et al. (2011), children had to judge for about 10 minutes on which side of the screen (the side with the sun or the side with the moon) they saw most dots, with the number of dots varying between 1 and 18. The dot patterns were controlled for perceptual variables using the procedure of Dehaene et al. (2005), meaning that on half of the trials dot size was held constant, and on the other half, the size of the total occupied area of the dots was held constant. There were number comparisons ratio 1:2, ratio 1:3; ratio 2:3; ratio 3:4, ratio 4:5 and ratio 5:6. In each trial, a black fixation cross (Arial, pt. 28) appeared in the middle of the white screen during 500ms and was followed by the stimulus, which remained for 5000 ms during the first test phase (*n*=5) and for 1202 ms during the next trials (*n* =10) and during the real test (*n* = 72). The practice items were administered to ensure that the participants understood the task instructions. Children were asked to respond as quickly and accurately. Accuracy and reaction time were recorded.

2.2.3. Logicial thinking skills

Logical thinking abilities were tested as with seriation and classification subtests of the Tedi-Math (Grégoire et al., 2004) at T1. Children had to seriate numbers (e.g., ‘Sort the cards from the one with the fewest trees to the one with the most trees’). In addition 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 internal consistency of task was good with Cronbach’s Alpha of .73.

2.2.4. Language skills

To get a picture of the oral language skills at T1 all the children were tested with the Clinical Evaluation of Language Fundamentals or the CELF-$_4$Nl (Semel, Wiig, & Secord 2008; Kort, Schittekatte, & Compaan 2008). The CELF-$_4$Nl assesses concepts and following of directions (children point to pictured objects in response to oral directions), word structure (children complete sentences using the targeted structures), recalling sentences (children imitate sentences presented by the examiner), formulating sentences (children formulate a sentence about visual stimuli using a targeted word or phrase), sentence structure (children point to a pictured object, person or activity), number repetition (children repeat a series of numbers forward and backwards), and familiar sequences (children name days of the week, count backward, orders other information while being timed). This results in a core language score, a receptive language index, an expressive language index, a language content index and a language structure index. This test was validated on 1280 children. The internal consistency was good, with Cronbach's alpha between .87 and .95.

2.2.5. Arithmetic

To assess early arithmetic skills in kindergarten (at T1) subtest five of the Tedi-Math was used. This subtest consisted of series of simple arithmetic operations. The child was presented simple arithmetic operations on pictures (e.g. 'Here you see two red balloons and three blue balloons. How many balloons are there together?' Cronbach's alpha was .84.

In grade 1 (at T2) hildren completed the Kortrijk aRrithmetic Test Revision (KRT-R; Baudonck et al., 2006) to test their arithmetic skills. The KRT-R is a standardized test which requires that children solve 30 simple calculations in a number-problem format (e.g., 16 - 12 = …), and 30 more complex calculations often in a word-problem format (e.g., 1 less than 8 is …) in first grade. The psychometric value of the test has been demonstrated on a sample of 3,246 children.

2.2.6. Intelligence

Intelligence was assessed at T1 with the Wechsler Preschool and Primary Scale of Intelligence or the WPPSI-III-NL (Wechsler, 2002; Hendriksen & Hurks, 2009). Children completed the three core verbal tests (information, vocabulary, and word reasoning) and the three performal tests (block patterns, Matrix reasoning, and concepts drawing).

2.3. Procedure

Each child was tested in kindergarten (1) individually in a quiet room of the school to obtain measures of logical thinking, counting and language skills. In addition intelligence, number estimation and early calculation skills were assessed. All children spoke Dutch well enough to understand the test instructions. One year later (T2), all children were tested again on their ability to solve simple calculations in a room at their school.

At first, the ***bivariate relations*** among all variables will be described.

In addition, several regression analyses will be conducted to study cross-sectional relationships with ***arithmetic skills among kindergarteners (at T1)***. The first regression analysis will be conducted on the two types of counting knowledge (procedural and conceptual knowledge) as predictors, since the two types of counting might represent theoretically different constructs (see Table 2). Moreover, a second regression analysis will be performed on the three tasks for estimation (number line estimation, number comparison and number naming) as predictors (see Table 2). Since these tasks may or may not represent the same construct in young children, they will not be combined into a composite for this study. Because of the low power, the contribution of the two counting constructs and the three estimation tasks will be evaluated separately before determining which constructs/tasks to include in the regression to evaluate hypothesis 1. The third regression analysis will be performed on the significant variables from regression 1 and 2 plus logical thinking and language as predictors for arithmetic skills as dependent measure (at T1). Moreover a fourth regression will be conducted as follow-up to the main hypothesis regression, given the strong role of language. In this regression the components of language (receptive language index, productive language index, content index and structure index) in relation to kindergarten arithmetic will be evaluated to determine if one or more components are especially relevant to explain variance in arithmetic skills among kindergarteners, controlling for counting and estimation.

Next a regression will be conducted with ***grade 1 arithmetic (T2)*** as outcome, controlling for kindergarten (T1) arithmetic. In this regression the significant variables from the previous (third and fourth) regressions will be included to look if once controlling for kindergarten arithmetic skills and relevant predictors in kindergarten language still predicts variance in grade 1 arithmetic.

3. Results

3.1. Bivariate relations among the constructs

For a correlation table of all measures (two arithmetic measures, T1 and TS), overall language and each of its components (assessed at T1), logical thinking (assessed at T1), the two types of counting (procedural and conceptual counting assessed at T1), the three tasks for estimation (number line estimation, number comparison and number naming assessed at T1), we refer to Table 1.

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Insert Table 1 about here

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The Table shows a significant relation between early calculation skills in kindergarten and the core language index, but also with the receptive, expressive, content and structure index in kindergarten. Moreover, there was a significant correlation between early calculation in kindergarten and procedural counting knowledge, number comparison and number naming, even with Bonferroni corrections for the number of correlations that were calculated. In addition Table 1 revealed a significant correlation between the skills of children in grade 1 to solve simple calculations and their core language index assessed in kindergarten. Moreover, there was a correlation between arithmetic at T2 and receptive language index (p =.001), and between PAE and number naming (p =.001).

3.2. **Variance in arithmetic skills among kindergarteners**

To examine the first hypothesis two preparatory regression analyses were conducted with variance in arithmetic skills among kindergarteners (T1) as outcome.

The first preparatory regression analysis was conducted to evaluate the contribution of the two counting constructs. The two types of counting knowledge were simultaneously entered as predictors (see Table 2).

The regression analysis was significant (F 2, 62) = 9.961, $p < .001$, $R^2 = .249$) for procedural counting knowledge (p =.005) and conceptual counting knowledge (p = .037; see Table 2).

There next preparatory regression analysis was conducted on the three estimation tasks simultaneously entered as predictors.

The regression was significant (F 3, 57) = 11.326, $p < .001$, $R^2 = .386$) for number comparison (p =.009) and number naming (p = .011) but not for number line estimation (p = .199; see Table 2).

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Insert Table 2 about here

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A third regression was used to evaluate the first main hypothesis on variance in arithmetic skills among kindergarteners. In this regression analysis the significant variables from regression 1 and 2 plus logical thinking and the core language index were simultaneously entered as predictors for kindergarten arithmetic skills . This cross-sectional regression was significant (F 6, 62) = 14.503, $p < .001$, R^2 = .608) with a trend for procedural counting knowledge (p =.097) and significant results for number naming (p=.007) and language ($p < .001$; see Table 3). Number naming explained 29.6% of the variance in arithmetic skills among kindergarteners. Procedural counting knowledge added 8% of explained variance to the prediction. Finally, the core language index explained 21.6% of the variance in arithmetic skills among kindergarteners (T1) controlling for number naming and procedural counting knowledge.

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Insert Table 3 about here

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Given the strong role of language, a fourth regression was conducted to deconstruct which component of language (e.g., receptive, expressive, content or structure) explained the variance in arithmetic skills among kindergarteners, controlling for number naming and procedural counting. This regression was significant (F 6, 56) = 15.782, $p < .001$, R^2 = .628) for procedural counting knowledge (p =.021), number naming (p=.002) and expressive language ($p < .001$; see Table 3).

Expressive language explained 24% of the variance in arithmetic skills among kindergarteners controlling for number naming and procedural counting knowledge.

3.3. Variance in grade 1 arithmetic

To examine the second hypothesis a regression was conducted with grade 1 arithmetic skills (T2) as outcome, controlling for variance in arithmetic skills among kindergarteners (T1). The variables that were significant (procedural counting knowledge, number naming) in the previous (third and fourthp regressions were added as predictors.

The regression with all these variables simultaneously entered as predictors was significant (F 4, 62) = 8.110, $p < .001$, $R^2 = .359$) with only significant results for the expressive language ($p = .035$; see Table 4).

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Insert Table 4 about here

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A stepwise regression revealed that kindergarten arithmetic predicted 29.9% of the variance in grade 1 arithmetic skills (F 1, 62) = 26.02, $p < .001$). In addition productive language added 4.6% to the prediction when controlling for kindergarten arithmetic (F 2, 62) = 15.78, $p < .001$, $R^2 = .345$).

4. Discussion

The importance of predictors for successful development of arithmetic has been demonstrated (e.g., Aunio & Niemivirta, 2010; Dickerson, Mayes, Calhoun, Bixler, & Zimmerman, 2009; Dowker, 2005; Kroesbergen, Van Luit, & Aunio, 2012). The aim of this study was to simultaneously tapp the contribution of counting, estimation, logical thinking, and language assessed in kindergarten to the acquisition of arithmetic skills. The current interest in these kindergarten skills is encouraged by the hope that, if those predictors, can be addressed as key components in remediation programs, children may not fall further behind.

The study replicated previous research on the relationship between counting and arithmetic (Stock et al., 2009; 2010). The cross-sectional analysis revealed that both types of counting knowledge (procedural and conceptual knowledge) predicted variance in arithmetic skills among kindergarteners. However when controlling for language, only a trend for procedural counting knowledge remained present.

Moreover, our findings underlined the value of estimation tasks in kindergarten. Number naming as estimation task explained a significant amount of the variance in arithmetic skills among kindergarteners controlling for language and counting skills. So we confirmed the findings of earlier studies (e.g., Desoete et al., Ceulemans, De Weerdt, & Pieters, 2012; Desoete & Grégoire, 2007) that estimation was related to early arithmetic achievement, supporting the hypothesis that good number representations can form a sound foundation for the arithmetic development. However the kindergarten estimation skills were no longer significant predictors for grade 1 arithmetic, controlling for kindergarten arithmetic and languange. Moreover, the three tasks for estimation appeared not to represent the same construct in young children, so they can better not be combined into composite scores. Number naming and number comparison tasks correlated significantly, but the correlation between number line estimation (PAE) and number comparison and number naming were no longer significant with the Bonferroni correction, meaning that the choice of paradigm to assess number representation might be an important choice.

In this study logical thinking skills assessed in kindergarten correlated signficantly with both arithmetic assessed in kindergarten and grade 1. However when other variables were added to explore the combined effect of these predictors, logical thinking no longer explained a significant amount of variance in arithmetic skills among young children.

Finally, this study addressed the gap in the literature about the relationship between kindergarten language and arithmetic. In line with Barner et al. (2009), Boonen, Kolkman and Kroesbergen (2011), and Negen and Sarnecka (2012), language explained variance in arithmetic skills among young children. The core language index was a significantly correlated with arithmetic skills among kindergarteners even when controlling for counting, estimation and logical thinking. Expressive language in kindergarten explained about one fifth of the variance in arithmetic skills among children. Moreover, expressive language predicted about 4% of the variance of grade 1 arithmetic when controlling for kindergarten arithmetic.

Limitations and future research

The current study has limitations that necessary raise questions for future research. It should be acknowledged that sample size is a limitation of the present study. Obviously sample size is not a problem for significant correlations or regressions. However, when analyses have insufficient power and were not significant, a risk of type 2- or β-mistakes (concluding from the cohort that there were no differences although in reality there were differences in the population) can not be excluded. Additional research with larger groups of children is indicated. Such study is currently being planned. Moreover, a number of options for future research can be pursued. There is no doubt that in many respects more in-depth research is needed on f.ex. as described by Siegler and Booth (2004) whether the median estimates of the Number Line Estimation Task in kindergarten are better fit by a logarithmic or linear function. In addition only accuracy in procedural calculation was studied. In addition, there might be different predictions for speed and accuracy and for arithmetic fact retrieval and procedural calculation skills. We believe that research data derived from such studies could improve our understanding of the mechanism of numeracy development.

Conclusion

The present study shows that hat language explains a substantial amount of variance in arithmetic skills among kindergarteners. Moreover, language predicts grade 1 arithmetic when controlling for kindergarten arithmetic. In addition, also number estimation (tested with a number naming task) explains a proportion of variance in arithmetic skills among kindergarteners, even when controlling for counting, language and logical thinking skills.

Such knowledge is necessary in order to inform targeted instruction and interventions that address the needs of children at risk, such as siblings of mathematical learning disabilities (Desoete, Praet, Titeca, & Ceulemans, 2013). Perhaps additional research can reveal if an intervention on language and/or number naming ability in kindergarten can increase arithmetic skills in first grade.

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Table 1

Correlations between arithmetics (T1 and T2), language, logical thinking, counting and estimation

	TM (T1)	1.	2	3	4	5	6	7	8	9	10	11	12
1. KRT-R (T2)	.527*	-	-	-	-	-	-	-	-	-	-	-	-
2. Lg. Core Ind.	.620*	.501*	-	-	-	-	-	-	-	-	-	-	-
3. Log. Think.	.509*	.438*	.411	-	-	-	-	-	-	-	-	-	-
4. Proc. Count.	.438*	.311	.205	.427*	-	-	-	-	-	-	-	-	-
5. Conc. Count.	.377	.206	.240	.532*	.349	-	-	-	-	-	-	-	-
6. NL PAE	-.368	-.332	-.387	-.282	-.337	-116	-	-	-	-	-	-	-
7. Numb Comp.	.473*	.340	.298	.301	.379	.312	-.232	-	-	-	-	-	-
8. Numb nam.	.544*	.276	.254	.393	.320	.352	-.426	.465*	-	-	-	-	-
9 Recept.Lang.	.553*	.400	.771*	.354	.224	.223	-.382	.300	.278	-	-	-	-
10 Exp. Lang.	.677*	.544*	.904*	.401	.218	.226	-.384	.357	.350	.709*	-	-	-
11 Lg. content	.561*	.450*	.787*	.388	.160	.292	-.365	.298	.358	.783*	.834*	-	-
12 Lg.structure	.601*	.458*	.927*	.375	.196	.194	-.341	.303	.300	.753*	.907*	.759*	-

Note. TM = Tedi-Math (arithmetic measure in kindergarten, Time 1), KRT-R = Kortrijk Arithmetic Test Revision (procedural mathematical skills in Grade 1, Time 2); Lg. Core Ind. = language core index; Log. Think. = logical thinking; Proc. Count. = Procedural counting; Conc.

Count. = Conceptual counting knowledge; NL PAE = Percentage Absolute Error on the numberline task; Numb Comp = Number comparison; Numb nam = number naming; Recept.Lang. = receptive language index; Exp.Lang. = expressive language index; Lg. content = language content index; Lg.structure = language structure index

* $p < .001$ (after Bonferroni adjustment)

Table 2

Predictions with arithmetic skills in kindergarten (at T1) as outcome

	Unstandardised Coefficients	β	t	*p*
Counting variables				
Constant	-6.478		-1.928	.059
Proc. counting	1.428	.350	2.928	.005*
Conc. counting	0.487	.255	2.135	.037*
Estimation variables				
Constant	-6.940		-1.533	.131
Number line PAE	-.104	-.153	-1.299	.199
Numb.comparison	.235	.317	2.703	.009*
Numb.naming	.193	.330	2.617	.011*

*$p \leq .05$ Note. PAE = Percentage Absolute Error, Numb. = number, Proc. = procedural knowledge, Conc. = conceptual knowledge

Table 3

Significant variables from Table 2 as predictions of arithmetic skills in T1 as outcome

	Unstandardised Coefficients	β	t	*p*
Constant	-24.187		-5.413	.000
Proc.counting	.672	.164	1.687	.097
Conc.counting	.053	.028	.274	.785
Numb.comparison	.067	.112	1.118	.268
Numb.naming	.161	.279	2.790	.007*
Core Language index	.191	.434	4.626	.000*
Logical thinking	.164	.102	.920	.362
Language variables				
Constant	-23.965		-5.413	.000
Proc.counting	.865	.209	2.378	.021*
Numb.naming	.170	.296	3.237	.002*
Receptive L index	.077	.209	1.415	.162
Productive L index	.290	.692	2.922	.005*
L content index	-.075	-.193	-1.089	.281
L structure index	-.069	-.167	-.784	.436

*$p \leq .05$ Note. PAE = Percentage Absolute Error, Numb. = number, Proc. = procedural knowledge, Conc. = conceptual knowledge

Table 4

Significant predictions of arithmetic skills in T2 as outcome

	Unstandardised Coefficients	β	t	*p*
Constant	-54.316		-1.574	.121
T1 arithmetic skills	1.466	.266	1.574	.121
Expressive Language	0.716	.310	2.153	.035*
Proc.counting	2.860	.127	1.072	.288
Numb.naming	0.087	.027	.218	.828

*p ≤ .05 Note. PAE = Percentage Absolute Error, Numb. = number, Proc. = procedural knowledge, Conc. = conceptual knowledge