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Language in the prediction of mathematical (dis)abilities ? Evidence from a longitudinal study following-up children from kindergarten till grade 2.

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Abstract

Previous studies suggested that early numeracy predict mathematical abilities and disabilities. Although there is evidence for a significant relationship between language and numeracy, it remains an open question to what extent mathematics is truly dependent on language. In addition the question on how different language components relate to children's mathematical performance remains unresolved.

This longitudinal study examined how receptive language, expressive language, the understanding of grammatical rules and the structure of language assessed in kindergarten were differentially related to children's early arithmetic skills in kindergarten and to their number knowledge, mental arithmetic skills and fact retrieval abilities in grade 1 and 2. A group of 132 children was followed-up from kindergarten till grade 2.

The relationship between counting and arithmetic and the value of number estimation was confirmed in this study. In addition, our data revealed that expressive language had a unique contribution of 30.1% in explaining the variance of early arithmetic skills in kindergarten. Moreover, there was a unique longitudinal prediction for expressive kindergarten language of 28.3% for number knowledge and of 22.1% for mental arithmetic in grade 1. Expressive language assessed in kindergarten still added 5% to the prediction of number knowledge in grade 2. Receptive language in kindergarten added 10.8% to the explained variance of fact retrieval proficiency assessed in grade 2.

Highlights

- There is a significant relationship between counting, number estimation and arithmetic
- Expressive language explains 30.1% of early arithmetic skills' variance in kindergarten.
- Expressive language in kindergarten predicts 28.3% of the number knowledge and 22.1% for mental arithmetic skills in grade 1.
- Expressive language assessed in kindergarten adds 5% to the prediction of number knowledge in grade 2.
- Receptive language in kindergarten adds 10.8% to the prediction of fact retrieval proficiency in grade 2.

Keywords: Arithmetic, expressive language , receptive language, number knowledge, fact retrieval, counting

1. Introduction

There is evidence for a significant relationship between language and formal mathematics (Bull & Johnston, 1997; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Geary, 1993; Jordan, Kaplan, Olah, & Locuniak, 2006; Jordan, Wylie, & Mulhern, 2010). However, it remains an open question to what extent mathematics is truly dependent on language and to what extent language has an additive value to other established predictors such as counting (Duncan et al 2007; Hannula, Räsänen, & Lehtinen, 2007; Passolunghi, Vercelloni, &

Schadee, 2007), logical thinking (Nunes et al., 2006) and number estimation (Ashcraft & More, 2012; Geary, 2011; Halberda, Mazzocco, & Feigenson, 2008)..

The importance of kindergarten in the development of numeracy is not ignorable. Aunola, Leskinen, Lerkkanen, and Nurmil (2004) revealed that when children have high levels of numeracy in kindergarten, their numeracy even increases between kindergarten and grade 2, whereas in children with lower levels of numeracy there is less improvement over the same period.

The present study aims to investigate language as a possible predictor in addition to the predictability of early arithmetic skills in young children by their counting, logical thinking and estimation skills

1.1. Counting in kindergarten and early arithmetic

Aunola et al. (2004) demonstrated that counting knowledge was the best predictor not only of the initial arithmetic performance level, but that it acted also as a measure of the subsequent growth in arithmetical performance. Stock and colleagues (2010) concluded that 87.50% of the children with mathematical learning disabilities (at age 7 to 8) could be correctly diagnosed in kindergarten by a combination of (procedural and conceptual) counting and estimation tasks.

There is substantial literature that sees counting as a unitary ability. Dowker however (2005) considers counting as the knowledge that 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 the child’s understanding of the essential counting principles: the stable order principle, the one-to-one-correspondence principle and the cardinality principle (LeFevre et al., 2006). Conceptual and procedural knowledge in kindergartners’ counting is well mapped (Dowker, 2005; Duncan et al., 2007; Hannula et al., 2007; Stock et al., 2010).

1.2. Logical thinking skills in kindergarten and early arithmetic

Logical abilities, as described by Piaget, are inherent to understand and make relational statements. Although Neo-Piagetian researchers questioned the causality of seriation and classification for understanding number (e.g., Grégoire, 2005; Lourenço & Machado, 1996), logical abilities in six year-old children remain a strong predictor for arithmetic abilities 16 months later after controlling for very differences in working memory (Nunes et al., 2006).

1.3. Number estimation in kindergarten and early arithmetic

A substantial amount of studies revealed that number representation is correlated with mathematical abilities (Ashcraft & More, 2012; Geary, 2011; Halberda, Mazzocco, & Feigenson, 2008). A Number Line Estimation (NLE) paradigm has often been used as an experimental measure of children's estimation of quantities. However there is some discussion on the NLE paradigm (e.g.Cohen & Blanc-Goldhammer, 2011; Cohen Kadosh, Muggleton, Silvanto, & Walsh, 2010; Defever, Sasanguie, Gebuis, & Reynvoet, 2011; Van Opstal & Verguts, 2011) and its relationship with proficient arithmetic. In addition the relationship between numerical magnitude comparison skills and mathematical performances remains unclear (Price, Palmer, Battista, & Ansari, 2012). Therefore 'number representation' will be the caption of data gathered by different protocols, such as number line estimation, number comparison and number naming tasks in this study.

1.4. Language in kindergarten and early arithmetic

Recently the value of including language as a measure has been stressed in the prediction of numeracy development (Purpura et al., 2011; Romano, Babchishin, Pagani, & Kohen, 2010; Sarnecka et al., 2007; Wiese, 2003). Moreover, Cowan and Renton (1996) already indicated that number words facilitate mathematical reasoning. Besides, there was evidence that a larger nominal vocabulary was found to be helpful in learning number words (Negen & Sarnecka, 2012). In addition, some studies (Barner, Chow, & Yang, 2009; Negen & Sarnecka, 2012) revealed that general measures of language development predicted number-word knowledge, although other studies (e.g., Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003) did not find such a link. To be conclusive, it remains unclear to what extent mathematics is truly dependent on language. Furthermore, the question about which component(s) of oral language are needed for the development of arithmetic abilities as oral language skills include a receptive pillar, an expressive pillar, the understanding of grammatical rules and the structure of language (Purpura et. al, 2011; Storch & Whitehurst, 2002) is still unanswered.

Receptive language refers to the capacity of the understanding of words and word classes (e.g., understanding words as 'small', 'add', 'different'). Expressive language refers to the ability of using those words or word classes to identify an object, person or activity in a correct way. The understanding of grammatical rules and its language structure finds its reflection in the way we build sentences and are also needed to solve word problems.

1.5. The current study

Although there is a lot of evidence that kindergarten skills are important predictors of later arithmetic achievement, we found the relationship between logical thinking, counting, number representation and language empirically being poorly documented. Therefore, an aim of this study was to replicate the link between logical thinking, counting skills and number representation in kindergarten and arithmetic in kindergarten and in elemenatary school. In addition we will try to analyze if the receptive, expressive, structure and content index of language provides additional longitudinal prediction on arithmetic. Besides, we aim to investigate the possibility to shorten the test (reducing irrelevant tasks in kindergarten) to be administered and therefore reducing costs to administer and improving scores because participants are less fatigued.

2. Method

2.1. Participants

In this study 132 children (48% girls) from the outskirts of Zele (Belgium) were tested in kindergarten (time T1), grade 1 (T2 and T3) and grade 2 (T4). Parental consent was obtained for each child. Most children came from working- and middle-class socio-economic backgrounds. Dutch was the only language spoken at home.

The first assessment was conducted in the last year of kindergarten (T1). The children's average age was 68 months (*SD* = 3.94). The mean intelligence of the sample was TIQ = 101.39 (*SD*=12.73), VIQ = 102.74 (*SD*=11.97), PIQ = 99.29 (*SD*=11.68).

2.2. Measures

2.2.1. Logical thinking skills

Logical thinking abilities were tested with the seriation and classification subtests of the Tedi-Math (Grégoire, Noël, & Van Nieuwenhoven, 2004) at T1. At first quantities had to be seriated (e.g., 'Sort the cards from the one with the fewest trees to the one with the most trees'). In addition they had to group cards in order to assess number classification (e.g., 'Make groups with the cards that go together'). The internal consistency of task is good with Cronbach's Alpha of .73.

2.2.2. 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 to 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 is 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 is good (Cronbach's Alpha = .85).

2.2.3. Language skills

To get a picture of the oral language skills in kindergarten (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 have to 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 have to point to a pictured object, person or activity), number repetition (children repeat a series of numbers forward and backwards), and recall familiar sequences (children name days of the week, count backward, order 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. The core Language score is a measure of general language ability that quantifies children's overall language performance. The Receptive Language index is a measure of listening and auditory comprehension. The Expressive Language index is the measure of expressive language skills. The Language Content index is the measure of various aspects of semantic development, including vocabulary, concept and category development, comprehension of associations and relationships among words, interpretation of information presented orally, and the ability to create meaningful, semantically and syntactically correct sentences. The Language Structure index is an overall measure of receptive and expressive components of interpreting and producing sentence structure. This test was validated on 1280 children. The internal consistency is good, with Cronbach's alpha between .87 and .95 in this sample.

2.2.4. Number estimation skills

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

In the **NLE-task**, children were asked to put a single mark on a numberline to indicate the location of a number. We used a 0-100 interval in line with Berteletti, Lucangeli, Piazza, Dehaene, and Zorzi (2010) and Booth and Siegler (2006). The task included three exercise trials and 30 test trials. It was a forced task and all children were presented with 25-cm long lines in the center of white A4 sheets. Stimuli were presented in three different formats, as Arabic numerals (e.g. anchors 0 and 100, target number 25), as spoken number words (e.g. anchors zero and hundred, target number twenty five), and as 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 (Dehaene, Izard, & Piazza, 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, Gebhardt and Hartnegg (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 number of correct responses were measured.

In the Number comparison task: the children have to estimate, compare and finally judge for about ten minutes which side of the screen shows the utmost of dots. This task is in line with Halberda and Feigenson (2008) and Inglis, Attridge, Batchelor and Gilmore. (2011), The number of dots varied between 1 and 18. The dot patterns were controlled for perceptual variables using the procedure of Dehaene et al. (2005), which means 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 1200 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.

2.2.5. Arithmetic

To get a picture of the arithmetic skills, early arithmetic was tested with the Tedi-Math (in kindergarten), number knowledge and mental arithmetic (in grade 1 and 2) were tested with a non-timed curriculum based test (KRT-R) and fact retrieval skills were tested with a timed test in grade 2.

To assess early arithmetic at T1 we used a subtest of the Tedi-Math, consisting 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?' The Tedi-Math was used and tested for conceptual accuracy and clinical relevance in previous studies (e.g., Desoete & Grégoire, 2006; Stock, Desoete, & Roeyers, 2010). Its reliability coefficient (Cronbach's alpha) was .84.

At T2 and T3 children completed the Kortrijk Arithmetic Test Revision (KRT-R; Baudonck et al., 2006) to test their untimed calculation skills. The KRT-R is a standardized curriculum-based math test on mental arithmetic (e.g., 16 - 12 = …), and number knowledge (e.g., 1 less than 8 is …) in first grade. The psychometric value of the test was demonstrated on a sample of 3,246 children. The reliability coefficient (Cronbach's alpha) was .93 .

At T3 children also completed the ***Arithmetic Number Fact Retrieval Test*** (Tempo Test Rekenen [TTR]; De Vos, 1992). It is a timed arithmetic test to assess fact retrieval with 200 arithmetic number fact problems (e.g., 2 + 5 = ...). Children have to solve as many number fact problems as possible within 5 minutes (addition, subtraction, multiplication, divisions, mix-up). The test was standardized in Flanders on a sample of 10,059 children (Ghesquière & Ruijssenaars,1994) . Cronbach alpha was .89.

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

At T1 (in kindergarten) all children were individually tested on counting, number estimation, logical thinking and language skills. In addition intelligence was assessed. Their Dutch level was sufficient to understand the test instructions. Six months later in Grade1 (= T2), all children were individually tested on their number knowledge and mental arithmetic ability. In January (=T3) of grade 2 half of the children were tested again on number knowledge, mental arithmetic and on fact retrieval skills.

A series of regressions were conducted with arithmetic in kindergarten (T1), grade 1 (T2) and grade 2 (T3) as outcome. The regressions investigated kindergartner's counting variables (procedural counting and conceptual counting assessed at T1) predicting arithmetic (at T1, T2 and T3).

The next regressions investigated kindergartner's estimation variables (number line, comparison and naming) as predictors for arithmetic (at T1, T2 and T3). Although it can be argued that these measures theoretically represent the same construct, the correlations suggested otherwise, so they were evaluated in a regression to determine if each one explained its unique variance in arithmetic.

Finally a series of regressions were conducted with the four language components assessed in kindergarten predicting arithmetic (at T1), number knowledge and mental arithmetic skills (at T2 and T3) and fact retrieval skills (at T3). To deconstruct language as predictor of outcome stepwise regressions are conducted with T2 and T3 arithmetic as outcome, controlling for T1 arithmetic. In these regressions the significant variables (by controlling the arithmetic skills of kindergarten from the regressions above) were be included to study the persistent prediction value of language on number knowledge, mental arithmetic and number fact retrieval in grade 1 and 2.

3. Results

3.1. Bivariate relations among the constructs

For a correlation table of all measures (four arithmetic measures, T1, T2, T3 and T4), overall language and each of its components (assessed at T1), logical thinking (assessed at T1), procedural and conceptual counting (assessed at T1), number line estimation (assessed at T1), number comparison (assessed at T1) and number naming (assessed at T1), we refer to Table 1.

Table 1 Correlations between arithmetic (T1, T2,T3), language, logical thinking, counting and estimation

	TM	KRT T2	KRT T3	TTR	LgCInd	LogThink	ProcCount	ConcCo	NLPAE	NumComp	NumNam	Rec L	Exp L	Lg cont
KRT(T2)	.462**	-	-	-	-	-	-	-	-	-	-	-	-	-
KRT(T3)	.677**	.679**	-	-	-	-	-	-	-	-	-	-	-	-
TTR(T3)	.262	.197	.383**	-	-	-	-	-	-	-	-	-	-	-
Lg. C Ind.	.486**	.458**	.557**	.234	-	-	-	-	-	-	-	-	-	-
Log. Think.	.548**	.402**	.460**	.184	.390**	-	-	-	-	-	-	-	-	-
Proc.	.470**	.263**	.466**	.227	.312**	.453**	-	-	-	-	-	-	-	-
Count.	.453**	.250**	.362**	.054	.231**	.477**	.372**	-	-	-	-	-	-	-
Con. Count	-.479**	.-344**	-.588**	-.291*	-.345**	-.384**	-.368**	-233**	-	-	-	-	-	-
NL PAE	.327**	.190*	.459**	.005	.251**	.249**	.254**	.151	-.159	-	-	-	-	-
Num Comp	.426**	.326**	.425**	.183	.261**	.379**	.278**	.217*	-.315**	.362**	-	-	-	-
Num nam.	.483**	.463**	.534**	.330*	.726**	.367**	.245**	.222*	-.383**	.231**	.261**	-	-	-
Rec.Lang.	.555**	.538**	.624**	.281*	.873**	.412**	.297**	.245**	-.435**	.270**	.309**	.731**	-	-
Exp. Lang.	.506**	.421**	.528**	.146	.743**	.398**	.287**	.234**	-.400**	.232**	.249**	.779**	.800**	-
Lg. cont	.499**	.456**	.519**	.324*	.918**	.393**	.250**	.204*	-.323**	.238**	.277**	.746**	.888**	.721**
Lg.struc														

Note. TM = Tedi-Math (arithmetic .measure in kindergarten, Time 1), KRT-R = Kortrijk Arithmetic Test Revision (procedural mathematical skills in Grade 1, Time 2); TTR=TempTestRekenen (fact retrieval); CDR=Cognitieve DeelVaardigheden; 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 ,T1 = time 1 (kindergarten), T2 = time 2 (start of grade 1), T3 = time 3 (grade 2) $^{**}p < .0005$ $^{*}p < .003$ (after Bonferroni adjustment*)*

There was a significant relationship between early calculation skills in kindergarten and the core language index and its pillars : the receptive, expressive, content and structure index in kindergarten even when Bonferroni corrected (see Table 1). At T2 there was a significant correlation between arithmetic and the language assessed in kindergarten. At T3 there was a significant correlation between procedural calculation and every pillar of language. In addition there was a significant correlation between fact-retrieval and language structure. At T4 there was a significant relation between procedural calculation in grade 2 and the core language index and its components. At T4 there was a correlation between fact retrieval and receptive language index, expressive language index and language structure index

3.2. Language associated with early arithmetic in kindergarten

Procedural counting knowledge (p <.001) and conceptual counting knowledge (p <.001) were significantly concurrently related to early arithmetic skills (F 2, 130) = 28.256, $p < .001$, $R^2 = .306$) in kindergarten.

In addition, number comparison (p =.016), number naming (p = .003) and number line estimation ($p < .001$) were related (as number estimation variables) significantly early arithmetic skills in kindergarten (F 3, 127) = 20.686 $p < .001$, $R^2 = .334$).

Moreover, the regression with the language variables (see Table 2) was significant (F 4, 129) = 14.796, $p < .001$, $R^2 = .321$) for the expressive language index (p =.032).

Table 2 Kindergarten predictors with arithmetic skills (at T1) as outcome

	Unstandardised Coefficients	β	t	*p*
Language variables				
Constant	-14.996		-4.794	.000
Expressive Language	.164	.401	2.173	.032*
Receptive Language	.053	.146	1.117	.226
Language structure Index	.035	.094	.665	.507
Language content .Index	-.015	-.036	-.215	.830
Stepwise predictors				
Constant	-9.909		-2.669	.009

Expressive language	.123	.301	4.050	.010**
Logical thinking	.339	.209	2.589	.011**
Procedural counting	.466	.149	1.971	.051*
Conceptual counting	.328	.177	2.416	.017*
Number line estimation	-.100	-.170	-2.269	.025*

*p ≤ .05 **p ≤ .01

The stepwise regression analysis (see Table 2) on all significant variables from the previous regressions revealed an explained variance of 30.1% of expressive kindergarten language for early arithmetic skills concurrently assessed (F (1, 127) = 54.165, $p < .001$). Logical thinking added 12% of explained variance (F (2, 127) = 45.491, $p < .001$). Procedural counting (F (3, 127) = 35.33, $p < .001$), conceptual counting (F (4, 127) = 28.833, $p < .001$) and number line estimation (F (5, 127) = 24.792, $p < .001$) added 4%, 2.2% and 2.1% respectively of explained variance. In total half ($R^2 = .504$) of the variance in early arithmetic skills could be attributed to the counting, estimation, language and logical thinking kindergarten predictors. The other variables (number comparison and number naming) were excluded from the prediction.

3.3. Kindergarten language predicting arithmetic in grade 1

Number knowledge in grade 1.

The longitudinal prediction of number knowledge in grade 1 by counting assessed in kindergarten (F (2, 126) = 3.562, $p = .031$, $R^2 = .054$) was a significant for procedural (p =.039) but not for conceptual counting knowledge (p =.415).

The longitudinal prediction (F (3, 125) = 6.399 $p < .001$, $R^2 = .136$) of number estimation (assessed in kindergarten) for number knowledge (in grade 1) was significant for the number line estimation (p = .002) but not for number comparison (p = .742) and number naming (p = .092).

The longitudinal prediction (F (4, 126) = 13.043, $p < .001$, $R^2 = .300$) of the language level assessed in kindergarten for number knowledge in grade 1 (see Table 3) was significant for expressive language (p <.001) but not for receptive language (p = .131), language content (p = .292) or language structure (p = .501)

Table 3 Kindergarten predictors with arithmetic in grade 1 (T2) as outcome

	Unstandardised Coefficients	β	t	*p*
Number knowledge	-.499		-0.152	.879
Expressive Language	.255	.612	3.275	.001**
Receptive Language	.075	.200	1.521	.131
Language structure Index	-.057	-.151	-1.058	.292
Language content Index	-.050	-.117	-0.674	.501
Stepwise predictors Constant	1.427		.456	.649
Expressive Language	.184	.442	5.419	.000**
Logical thinking	.364	.221	2.716	.008*
Mental arithmetic	-1.909		-0.492	.624
Expressive Language	.287	.599	3.117	.002**
Receptive Language	.127	.295	2.182	.031*
Language structure Index	-.065	-.149	-1.017	.311
Language content Index	-.120	-.243	-1.369	.173
Stepwise predictors Constant	2.611		.663	.509
Expressive Language	.158	.332	3.599	.000**

Early arithmetic	.297	.256	2.779	.006*

*p ≤ .05 **p ≤ .01

To deconstruct the value of language, a stepwise regression analysis (see Table 3) was conducted on all significant variables from the previous regressions. The analysis variables revealed an explained variance of 28.3% for expressive kindergarten language (*F* (1, 124) = 48.452, $p < .001$). Adding logical thinking as kindergarten predictor (*F* (2, 124) = 29.166, $p < .001$, $R^2 = .182$) augmented the prediction with 4%, explaining 32.3% of explained variance in mental arithmetic (see Table 4). The other variables (procedural counting knowledge, number line estimation) were excluded from the prediction.

Mental arithmetic in grade 1

The longitudinal prediction of mental arithmetic in grade 1 by counting assessed in kindergarten was significant (*F* 2, 126) = 8.263, $p < .001$, $R^2 = .118$) for conceptual ($p = .010$) and procedural ($p =.049$) counting knowledge.

The prediction by the kindergarten's number sense was also significant (*F* 3, 125) = 6.219 $p < .001$, $R^2 = .133$) for number naming ($p = .021$) and for the number line estimation ($p = .016$) but not for number comparison ($p = .713$).

Finally, the kindergarten language components (see Table 3) predicted mental arithmetic in grade 1 (*F* 4, 126) = 10.749, $p < .001$, $R^2 = .261$), with significant results for expressive ($p = .002$) and receptive language ($p =.031$).

Table 3 Kindergarten predictors with arithmetic in grade 1 (T2) as outcome

	Unstandardised Coefficients	β	t	*p*
Number knowledge	-.499		-0.152	.879
Expressive Language	.255	.612	3.275	.001**
Receptive Language	.075	.200	1.521	.131
Language structure Index	-.057	-.151	-1.058	.292

Language content Index	-.050	-.117	-0.674	.501
Stepwise predictors				
Constant	1.427		.456	.649
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Logical thinking	.364	.221	2.716	.008*
Mental arithmetic				
	-1.909		-0.492	.624
Expressive Language	.287	.599	3.117	.002**
Receptive Language	.127	.295	2.182	.031*
Language structure Index	-.065	-.149	-1.017	.311
Language content Index	-.120	-.243	-1.369	.173
Stepwise predictors				
Constant	2.611		.663	.509
Expressive Language	.158	.332	3.599	.000**
Early arithmetic	.297	.256	2.779	.006*

*p ≤ .05 **p ≤ .01

The stepwise regression analysis on the significant kindergarten variables revealed an explained variance of 22.1% for expressive kindergarten language predicting mental arithmetic assessed in grade 1 (F (1, 124) = 34.869, p < .001). Adding logical thinking as kindergarten predictor (F (2, 124) = 22.248, p < .001) the prediction augmented with 4.6%, explaining 26.7% of the variance in mental arithmetic (see Table 3). The other variables (procedural counting knowledge, conceptual counting knowledge, number line estimation, number naming, kindergarten arithmetic and receptive language) were excluded from the prediction.

3.4. Kindergarten language predicting arithmetic in grade 2

Number knowledge in grade 2.

Half of the children were followed-up in grade 2. The longitudinal prediction of number knowledge in grade 2 by counting assessed in kindergarten (F (2, 59) = 6.215, p = .004, R^2 = .179) was a significant for procedural (p =.009) but not for conceptual counting knowledge (p =.256).

The longitudinal prediction (F (3, 57) = 12.590 p < .001, R^2= .412) of number estimation (assessed in kindergarten) for number knowledge (in grade 2) was significant for the number line estimation (p < .001) but not for number comparison (p = .107) and number naming (p = .600).

The longitudinal prediction (F (4, 59) = 10.956, p < .001, R^2= .443) of kindergarten's language skills for number knowledge in grade 2 (see Table 4) was significant for expressive language (p = .002) and for receptive language (p = .047). Language content (p = .416) and language structure (p = .116) were no longer significant.

Table 4 Kindergarten predictors with arithmetic in grade 2 (T3) as outcome

	Unstandardised Coefficients	β	t	*p*
Number knowledge	-11.530		-3.087	.003
Expressive Language	.328	.886	3.191	.002**
Receptive Language	.111	.350	2.028	.047*
Language structure Index	-.058	-.166	-0.819	.416
Language content Index	-.144	-.405	-1.588	.118
Stepwise predictors				
Constant	2.639		.613	.542
Early arithmetic	.225	.270	2.080	.042*
Number line estimation	-.162	-.339	-3.218	.002**
Expressive language	.111	;302	2.486	.016*

Mental arithmetic		-7.324			-1.629	.109
Expressive Language		.324		.808	2.615	.012*
Receptive Language		.093		.270	1.406	.165
Language structure Index		-.049		-.129	-0.574	.569
Language content Index		-.156		-.404	-1.427	.159
Stepwise predictors						
Constant	9.016				9.062	.000
Early arithmetic	.509		.571		5.211	.000**
Fact retrieval		17.923			1.306	.198
Expressive Language		.372		.345	0.966	.339
Receptive Language		.405		.420	1.952	.057*
Language structural Index		-.594		-.573	-2.160	.036*
Language content Index		.151		.143	0.435	.665
Stepwise predictors						
Constant	23.348				2.011	.050
Receptive Language	.316		.329		2.511	.015*

$*p \leq .05$ $**p \leq .01$

To deconstruct the value of language, a stepwise regression analysis was conducted on all significant variables from the previous regressions. The analysis variables revealed an explained variance of 41.8% for early arithmetic (F (1, 57) = 40.194, p < .001). Adding number line estimation as kindergarten predictor (F (2, 57) = 29.087, p < .001) augmented the prediction of explained variance in mental arithmetic in grade 2 with 9.8%. Adding expressive language as predictor (F (2, 57) = 29.087, p < .001) added another 5% of explained variance, leading to 56.4% of explained variance in mental arithmetic in grade 2. The other variables (procedural counting knowledge, logical thinking and receptive language) were excluded from the prediction.

Mental arithmetic in grade 2

The longitudinal prediction of mental arithmetic in grade 2 by counting assessed in kindergarten was significant (F (2, 59) = 10.224, p < .001, R^2= .264) for conceptual (p = .029) and procedural (p =.006) counting knowledge.

The longitudinal prediction was also significant (F 3, 57) = 7.187 p < .001, R^2= .285) for number line estimation (p = .007) but not for the number comparison (p = .060) or number naming (p = .557)

Finally, the kindergarten language components (see Table 4) predicted mental arithmetic in grade 2 (F 4, 59) = 6.209, p < .001, R^2= .311), with significant results for expressive language (p =.012).

The stepwise regression analysis on the significant kindergarten variables revealed an explained variance of 32.7% for early arithmetic skills predicting mental arithmetic assessed in grade 2 (F (1, 57) = 27.151, p < .001). The other variables (procedural counting knowledge, conceptual counting knowledge, number line estimation, expressive language and logical thinking) were excluded from the prediction.

Timed fact retrieval skills in grade 2

The longitudinal prediction of the proficiency of solving timed fact retrieval skills in grade 2 was not significant (F (2, 54) = 1.447, p = .245) predicted by conceptual (p = .806) or procedural (p =.104) counting knowledge in kindergarten.

There was no longitudinal prediction (F 3, 52) = 1.713 p= .177) for number line estimation (p = .124), number comparison (p = .922) or number naming (p = .465)

However, the kindergarten language components (see Table 4) predicted fact retrieval skills in grade 2 (F 4, 54) = 3.098, p = .024, R^2= .199), with marginally significant results for receptive language (p =.057) and significant results for the language structure index (p =.036).

The stepwise regression analysis on the significant kindergarten variables revealed an explained variance of 10.8% for receptive language skills predicting fact retrieval proficiency assessed in grade 2 (F (1, 53) = 6.303, p = .015). The other variables (logical thinking and early arithmetic) were excluded from the prediction.

Discussion

Previous studies suggested that early numeracy predict mathematical abilities and disabilities. Several studies revealed that typical achieving children perform significantly better than children with mathematical disabilities on conceptual and procedural counting knowledge and on magnitude comparison assessed in kindergarten (Dowker, 2008; Nunes et al., 2006; Sarnecka & Carey, 2008; Stock et al., 2010).

The relationship between **counting** and arithmetic (Stock, Desoete, & Roeyers, 2009; 2010) was reconfirmed in this study. Procedural and conceptual counting knowledge assessed in kindergarten were concurrently related to early arithmetic skills with an explained variance of 30.6% in kindergarten. Number knowledge in grade 1 could be predicted by procedural counting knowledge (5.4% explained variance). Mental arithmetic in grade 1 could be predicted by conceptual and procedural counting knowledge in kindergarten (11.8% explained variance). Moreover in grade 2 number knowledge could by predicted (17.9% explained variance) by procedural counting knowledge and mental arithmetic could be predicted by (26.4% explained variance) conceptual and procedural counting knowledge. Counting knowledge in kindergarten did not predict significantly the fact retrieval skills in grade 2.

In this study the value of **number estimation** variables was confirmed. A previous study (Desoete, Ceulemans, De Weerdt, & Pieters, 2012) revealed that number estimation in kindergarten was predictable related to procedural calculation one year later and fact retrieval two years later. Children with MD had already had deficits in number comparison in kindergarten. The concurrent relationship between **n**umber comparison, number naming and number line estimation and early arithmetic skills in kindergarten (explained variance 33.4%) was confirmed. In addition, the longitudinal prediction of number line estimation assessed in kindergarten for number knowledge in grade 1 (explained variance 13.6%) was demonstrated and mental arithmetic in grade 1 could be predicted by a number line estimation and a number naming paradigm (explained variance 13.3%). In addition, the number line task made in kindergarten predicted 41.2% of the variance of number knowledge and 28.5% of the variance in mental arithmetic in grade 2. The prediction for fact retrieval in grade 2 was not significant. To conclude, these findings underline the value of estimation tasks in kindergarten, confirming the findings of earlier studies (e.g., Desoete et al., 2012; Desoete & Grégoire, 2007) that number estimation was related to early arithmetic achievement, supporting the hypothesis that good number representations could form a solid foundation for the arithmetic development.

In addition, **language** in kindergarten was investigated as cognitive predictor for mathematical abilities. In line with previous studies revealing a significant relationship between language and mathematics (e.g., Hooper et al., 2010; Jordan et al., 2010; Purpura et al., 2011) was present.

Especially expressive language revealed to be an important predictor. In kindergarten, expressive language predicted for 30.1% the variance of early arithmetic skills concurrently assessed on top of the other predictors.

Moreover, there was a longitudinal prediction of 28.3% for expressive kindergarten language on top of the prediction of logical thinking skills for number knowledge in grade 1. Expressive and receptive language assessed in kindergarten predicted mental arithmetic in grade 1 ($R^2 = .261$). The stepwise regression analysis revealed the importance and explained variance of 22.1% for expressive kindergarten language.

In addition there was a significant longitudinal prediction ($R^2 = .443$) of language assessed in kindergarten for number knowledge in grade 2, with expressive and receptive language as significant kindergarten predictors. The stepwise regression however especially revealed the importance of early arithmetic with expressive language adding 5% of explained variance to the prediction of number knowledge in grade 2. Moreover, the kindergarten language components also predicted mental arithmetic in grade 2 ($R^2 = .311$), with significant results for expressive language. However the stepwise regression analysis demonstrated especially the importance of early arithmetic skills, excluding language from the prediction of mental arithmetic in grade 2. Finally there was an explained variance of 10.8% for receptive language skills predicting fact retrieval proficiency assessed in grade 2. To conclude, this study addressed the a 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 was an important arithmetic predictor from kindergarten. Especially expressive language index seemed important to predict number knowledge (in grade 1 and 2) and mental arithmetic (in grade 1). Receptive language in kindergarten was a predictor for number knowledge in grade 1 and fact retrieval skills in grade 2. More research in needed to understand why and these skills relate to children's arithmetic performances in kindergarten and elementary school.

All studies have their limitations. 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't be excluded. Additional research with larger groups of children (certainly in grade 2) is indicated.

However, the findings from this study suggest that language should not be ignored as predictor for mathematical abilities and disabilities. A test on expressive language seems indicated to predict number knowledge and mental arithmetic. Receptive language adds to the prediction of fact retrieval proficiency. In addition, 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. Perhaps additional research can reveal if an intervention on language ability in kindergarten can increase arithmetic skills in first grade.

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