DRIVING FORCES BEHIND ARITHMETIC:
THE EVOLUTION FROM KINDERGARTEN TO GRADE 2

Magda Praet

UNIVERSITEIT GENT
FACULTEIT GENEESKUNDE EN GEZONDHEIDSWETENSCHAPPEN

Driving Forces behind Arithmetic:

the evolution from kindergarten to grade 2

Magda Praet

Promotor: Prof. Dr. Paul Van Cauwenberge
Copromotor: Prof. Dr. Anne Desoete

Proefschrift ingediend tot het behalen van de academische graad van Doctor in de Gezondheidswetenschappen
2014

Contents

ACKNOWLEDGMENTS

Ik apprecieer bijzonder de betrokkenheid van Prof. Dr. Paul Van Cauwenberge voor dit proefschrift dit niettegenstaande zijn veeleisende universitaire functie. Prof. Dr. Annemie Desoete zou ik willen zeggen “ zonder jouw enthousiasme, je gedrevenheid, je kennis, je volharding, je grenzeloos optimisme maar vooral je mensenkennis was dit proefschrift er gewoon niet” .

Daarnaast vermeld ik ook graag Dr. Anne Sieben voor haar feedback. Wat hebben we samen veel opgestoken van de neurologie hieromtrent. Ik kijk al uit naar jouw proefschrift !

Aan de oorsprong van dit proefschrift lag “ een Spielerei” een drang om iets gecomputeriseerds te ontwerpen voor kleuters met als doel hun prenumerieke kennis te doen toenemen. Op dat traject heb ik Dirk Vermeulen leren kennen en samen hebben we effectief een programma ontworpen dat een impact heeft op prenumerieke vaardigheden. Dirk, nogmaals bedankt om je kennis te willen delen, je onvoorwaardelijk enthousiasme voor het project en het plezier dat we beleefden bij het ontwerpen. Ik denk dat hoofdstuk 5 je wel bijzonder zal interesseren.

Daarnaast wil ik ook Ivo de Wispelaere bedanken voor zijn grafische inbreng.

Ik wens ook alle kinderen, ouders, leerkrachten en directies te bedanken die deelnamen aan dit onderzoek. Zonder jullie deelname was er van dit doctoraat geen sprake. Daarnaast waardeer ik ook alle hulp die de masterproefstudenten van UGent me geboden hebben.

Dank ook aan mijn broers en zussen: mijn energie- en steunbronnen met dank aan mijn zus Prof. Dr. Marleen Praet in het bijzonder.

Luc, het waren wel véél avonden hé. Gelukkig was Smoetie en later Vlekje er om je gezelschap te houden. Bedankt dat je me die kans gegeven hebt.

Magda
2 juli 2014

I. INTRODUCTION

Chapter 1
GENERAL INTRODUCTION

"The study of math, like the Nile, begins in minuteness, but ends in magnificence."- *Charles Caleb Colton*

The M-decreet (Measures for pupils with specific educational needs; Flemish Ministry of Education and Training, 2014) recently wanted to promote the increasing inclusion of low performing children in mainstream educational settings. Although therapists often consider language as a stumbling block for arithmetic, the amount of literature in this arithmetic predictor does not match this concern. The theoretical background of this doctoral dissertation will be discussed in this chapter, along with the research objectives. An overview of this dissertation will also be provided in the chapters included.

IMPORTANCE OF ARITHMETIC

It is hard not to overemphasise the importance of arithmetic in our world. Arithmetic is a cornerstone of our society. It determines use of time (Ruijssenaars & van Luit, 2007) and relates to distance and finance (Grégoire & Desoete, 2009). Arithmetical skills are crucial for occupational success and are a requirement for the 21st century (Browder, Jimenez, Spooner, Saunders, Hudson, & Bethune, 2013). It is through numerical literacy (numeracy) that students will be able to see how arithmetic rules our actual world through new technology.

The lack of arithmetical skills affects people's ability to gain full-time employment and often limits employment options to manual and, often, low paying jobs (Dowker, 2005). Low arithmetic proficiency has consequences for health care. Children with a lack of arithmetical skills are prone to encounter difficulties in society (Parsons & Bynner, 2005) and need more help at school (Parsons & Bynner, 2005).

Between 5 and 10% of students have learning difficulties in arithmetic before graduating from high school (Geary, Baily, Littlefield, Wood, Hoard, & Nugent, 2009). Moreover, difficulty with arithmetic is a problem in almost every country (Reigosa-Crespo, Valdés-Sosa, Butterworth, Estévez, Rodréguez, Santos, Torres, Suàrez, & Lage, 2012).

In this thesis, the term 'arithmetical skills' is restricted to 'simple' arithmetic skills (e.g., addition and subtraction procedures and facts).

In addition Morton and Frith (Morton, 2004; Morton & Frith, 1995) described ***three levels*** to examine skills, namely the biological, cognitive and behavioural levels (see Figure 1). Within this doctoral research we focused on the cognitive and behavioural level.

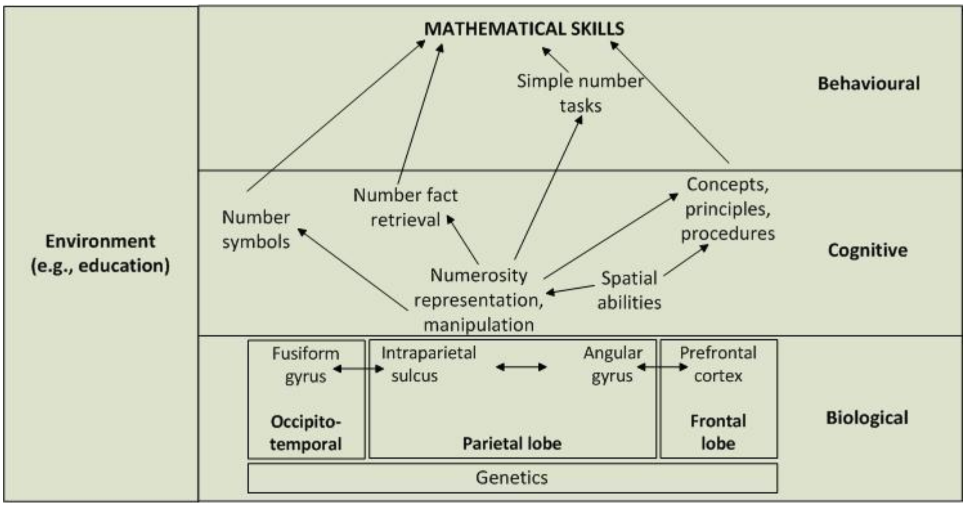


Figure 1. Three levels. Based on "From Dyscalculia: from brain to education" by B. Butterworth, S. Varma, and D. Laurillard, 2011, Science, 332, p. 1050.

In elementary school children a recent cluster analysis on the **behavioural level** revealed the need for differentiating between procedural calculation and fact retrieval (Geary, 1993, 2004; Pieters, Roeyers, Rosseel, Van Waelvelde, & Desoete, 2014; Robinson, Menchetti, & Torgesen, 2002; Temple, 1991).

On the **cognitive level**, several (contradictory) models have tried to describe the quantity processing needed for arithmetic in children. A special interesting model, when studying language and number line representation, is offered by the model of Dehaene.

Dehaene (1992) described three interconnected number systems (see Figure 2): *an auditory verbal system* based on the phonological representation of counting words, a non-verbal *visual system* and the *analogue magnitude code.* The dialogue between these three number-representation levels creates an integrated quantity-representation pathway, according to Dehaene (2001). The analogue magnitude code is especially needed for number comparison and approximate calculation. In order to compare (symbolic) Arabic numerals, quantities have to be transformed into (asymbolic) mental quantities (Dehaene, 1995). The visual system is handling parity judgments and multi-digit operations. The auditory-verbal word is needed, making use of general language modules, to have access to and retrieve stored arithmetic facts.

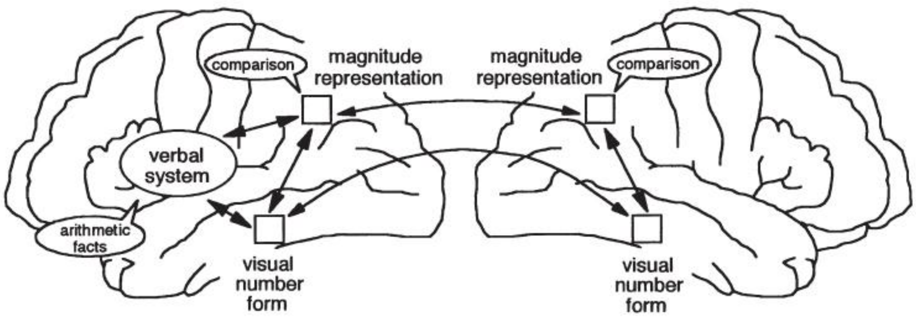


Figure 2: Anatomical implementation of the *triple-code model* on the external view of the hemispheres (From; Dehaene & Cohen, 1995, "Towards an anatomical and functional model of number processing" p88)

At a ***biological level***, arithmetic seems to depend on several areas in the brain. Figure 1 illustrates the link between the cortex and numerosity representations (Butterworth, Varme & Laurillard, 2011).

EARLY ARITHMETIC

Children develop skills even before they enter formal schooling. According to developmental theory, children’s capacity for arithmetic emerges from a cumulative process (Entwisle, Alexander, & Olson, 2005).

Several skills have been suggested as being cognitive factors that play a role in the development of initial arithmetical performance and, eventually, as early markers for arithmetical difficulties (Dowker, 2005; Van De Rijt, Van Luit, & Pennings, 1996; Van Luit, 2002).
Studies have lent support to the predictive value of the following early numerical skills: logical thinking skills, counting, subitizing, magnitude comparison and estimation. A short definition will be provided for each of the early numerical competencies, followed by a demonstration of the importance of this competency for later arithmetical functioning. In addition, this doctoral study aims to expand these predictors by adding language as a predictor for arithmetic skills in young children.

- ***Logical thinking skills***

For many years, logical thinking skills in kindergartners were considered the most important, unique markers in the development of arithmetic. In 1941, Piaget formulated that, from a cognitive point of view, there are four logical abilities that are conditional for developing arithmetic: seriation, classification, conservation and inclusion (Piaget & Szeminska, 1941).

Classification can be defined as the ability to sort objects by similarity. It points to the cardinality of a set (e.g., ‘How many trees do you see on this picture?’).

Inclusion can be described as the ability to make hierarchical classifications.

Seriation can be considered as the ability to sort, based on differences in a specific dimension. We are hereby dealing with ordinal numbers (e.g., ‘Show me the second house in a series of trees and houses’).

Finally, ***conservation*** can be defined as the knowledge that adding or removing items can only change quantity. By acquiring the conservation principle, the child has the ability to think in a reversible way. This skill is needed to solve reversal addition and subtraction tasks (e.g., ‘2 + _ = 6).

Logical abilities have been used through the years as a measure of academic readiness (Anderson, Anderson, & Thauberger, 2008). Although Piaget’s theory has received a lot of criticism (Lourenço & Machado, 1996), the importance of logical abilities is currently recognised. Even after controlling for differences in working memory, logical abilities in six-year-old children remained strong predictors for mathematical abilities 16 months later (Nunes, Bryant, Evans, Bell, Gardner, Gardner, & Carraher, 2006). In addition, children who were successful in logical thinking tasks performed better on arithmetic tests, with mastery of seriation abilities having the strongest predictive power (Grégoire, 2005).

- ***Counting***

Besides the Piagetian abilities, the neo-Piagetian area of counting also seems to be important in developing adequate mathematical skills (Dowker, 2008; Sarnecka, & Carey, 2008). Dowker (2005) suggested that counting knowledge is not a unitary concept, but can be subdivided into procedural and conceptual aspects. Although closely related to each other, these two aspects seem to be mastered separately (Dowker, 2005).

Procedural counting knowledge is defined as children’s ability to perform a mathematical task, for example, being successful in determining that there are five objects in an array (Koponen, Aunola, Ahonen, & Nurmi, 2007; LeFevre, Smith-Chant, Fast, Skwarchuk, Sargla, Arnup, ….. Kamawar, 2006).

This knowledge also includes the ability to count forwards and backwards easily. Geary (2004) suggests that procedural counting knowledge is supported by language systems. LeFevre et al. (2006) draw the conclusion that procedural counting knowledge (with respect to both accuracy and speed) increases linearly from kindergarten to grade 1. A lack of procedural counting knowledge is associated with problems in children with mathematical learning disorders regardless of their reading skills or IQ (Geary, 2007).

There are two explanations for this prominent role of counting knowledge (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Mazzocco & Thompson, 2005). First of all, procedural knowledge can appeal to all arithmetic-related information (Aunola et al., 2004; Van De Rijt & Van Luit, 1999). This in turn will permit other cognitive resources to devote themselves to more complex tasks, such as problem solving (Gersten & Chard, 1999; Resnick, 1989) and applying arithmetic strategies for addition, subtraction (LeFevre et al., 2006) and multiplication (Blöte, Lieffering, & Ouwehand, 2006). Secondly, procedural counting knowledge can be used as a back-up strategy for retrieval in learning new arithmetic knowledge (Jordan, Kaplan, Nabors, & Locuniak, 2006).

Conceptual counting knowledge on the other hand, reflects a child's understanding of why a procedure works or whether a procedure is legitimate (Bisanz & LeFevre, 1992; Hiebert & Lefevre, 1986; LeFevre et al., 2006). Conceptual counting knowledge can be defined as the understanding of the five counting principles formulated by Gelman and Galistel (1978), with three essential principles (i.e., word-object correspondence, stable order, and cardinality) and two unessential principles (i.e., abstraction and order irrelevance) since these two principles do not result in incorrect counting.

*The **one-to-one correspondence principle*** involves the understanding that each individual item can only be counted once. Gelman and Galistel (1978) stated that partitioning has to be coordinated in order to follow this principle (the child has to keep track, step-by-step, of the items still to be counted and those that have already been counted) and tagged (the summing up of each tag, one at a time) in such a way that these two processes both begin and end together. Children were found to be able to partition appropriately as young as 3 years old (Potter & Levy, 1968; Sophian, 1988). Wynn (1992) even found evidence of comprehension of the one-to-one principle in children aged 2 to 3, while Briars & Siegler, 1984 showed a good understanding of the principle might not be established until age 5.

The stable order principle requires a stable list that is as long as the number of items in the array (Gelman & Galistel, 1978). The extent to which children are able to adhere to this principle is strongly related to set size (i.e. the larger the set size, the more difficulties the child will experience following the principle). There is evidence (LeFevre, et al., 2006) that some children have established this principle in kindergarten. Most children in grade 1 have mastered an understanding at an “adult” level (Stock, Desoete, & Roeyers, 2009).

The cardinality principle reflects the understanding that the number tag applied to the final item in the set is the representation of the total number of items in the set (Gelman & Galistel, 1978). In other words, the child must be able to indicate the last assigned number represents the numerosity of the array. This principle incorporates the one-to-one correspondence and stable order principles and will, therefore, develop later. There is a continuous debate about the age children master this principle. Gelman and Meck (1983) suggested that all children master the principle by age 3. However, other studies suggest children have barely started conquering an initial understanding at age 3 and a half (Wynn, 1992) and sometimes not until 5 years of age (Freeman, Antonucci, & Lewis, 2000). A lack of understanding of this principle is usually evidenced when after counting an array of objects the last number counted does not equal the answer to the question “how many are there all together?”

There are also two non-essential principles: abstraction and order irrelevance.
The abstraction principle involves the understanding that the essential principles can be applied to all countable elements (Gelman & Galistel, 1978).
The order irrelevance principle states there is order independency in tagging (Gelman & Galistel, 1978).

Conceptual and procedural knowledge in kindergartners’ counting is well documented. In a study Johansson (2005) revealed that scores on procedural counting knowledge could predict arithmetical problems. In addition, children aged nine or ten years with arithmetical difficulties still had difficulties counting forwards and backwards from different starting numbers (Houssart, 2001). Counting knowledge has been identified as strongly predictive component of number sense for arithmetic skills (Geary, 1993; Stock, Desoete, & Roeyers, 2007). Two studies found that a combined measure of procedural counting and conceptual knowledge was related to maths at that particular time (Jordan, Kaplan, & Locuniak, 2007; Stock et al., 2009). A lot of studies have shown the involvement of counting knowledge across different time periods (Aunola et al., 2004; Lefevre et al., 2006; Kamawar, Lefevre, Bisanz, Fast, Skwarchuk, Smith-Chant, & Penner-Wilger, 2010. Cirino (2011) focused on procedural counting knowledge and maths outcomes. Several researchers (Geary, Hoard, & Hamson, 1999; Koponen et al., 2007; LeFevre et al., 2006, LeFevre, Bisanz, Skwarchuk, Smith-Chant, Fast, Shanahan, … Watchorn, 2008) found a relationship between conceptual counting knowledge and maths performance both at a single time point and across time points.

- ***Comparison, estimation***

Comparison is the ability to discriminate two quantities and to point out to the largest of both (Gersten, Clarke, Jordan, Newman-Gonchar, Haymond, & Wilkins, 2012).
Comparison relies on the approximate number system (ANS) to determine, especially larger numerosities, in an approximate manner (Halberda & Feigenson, 2008). The ANS is one of the two numerical systems in humans that have been documented (Cutini & Bonato, 2012; Furman & Rubinsten, 2012). The second system is called *Objects Tracking System* (OTS). OTS is a system that supports subitizing (see further). Both mechanisms act totally different on number range, upper limit, speed, accuracy cognitive load (e.g., Kahneman, Treisman, & Gibbs, 1992; Meck & Church, 1983) and neural substrates (e.g., Ansari, Lyons, Van Eitneren, & Xu, 2007, Demeyere, Lestou, & Humphreys, 2010; Vetter, Butterworth, & Bahrami, 2011).
Various researchers (De Smedt, Verschaffel, & Ghesquière, 2009; Holloway & Ansari, 2009) proved that number comparison in the development of arithmetic was important.

Estimation is often tested by the number line estimation task. The **number line estimation task** requires quantities (in three formats) to be placed on a line. The position of these Arabic numerals, number words and dot arrays are a reflection of the value, as the child perceives it. However there are other paradigms, such as the number comparison and the number naming task. In the **number comparison task** children have to judge on which side of the screen they have seen most dots. This task requires the ability to understand the numerical magnitude of the presented stimuli, since it involves a comparison with the second number or dot pattern. In addition there is the **number naming task** where children have to say aloud the number of black squares they saw on the screen. In this task children have to make an association or 'translation' between a nonverbal representation and a verbal label. They are mapping number words to preverbal magnitudes.

Research indicates that (in the number line estimation task) the gain in precision of number line judgments is characterized by a developmental transition from a logarithmic representation to a linear one, suggesting a changing representation with increasing formal schooling (Siegler & Booth, 2004; Siegler & Opfer, 2003). A logarithmic representation compresses the distance between magnitudes at the middle and upper ends of the interval (Siegler & Booth, 2004), whereas a linear representation provides an adequate reflection of the actual numbers. The age, at which this shift occurs, depends upon the numerical context (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010). For a 0-100 interval this shift is situated in the second grade (Siegler & Booth, 2004). Until recently, most research on number line estimation focused on the positioning of Arabic numerals – whether or not read aloud– on a number line (e.g., Berteletti et al., 2010; Siegler & Booth, 2004; Siegler & Opfer, 2003).

Although several studies support the importance of number line judgments for arithmetic ability, there is no consensus about the predictive value of the number line on arithmetical achievements (Mazzocco & Thompson, 2005; Siegler & Booth, 2004).

➢ ***Subitizing***

Subitizing is defined as preverbal number magnitude processing: the rapid (40-100 ms/item), automatic and accurate assessment of small quantities (e.g., Nan, Knösche, & Luo, 2006; Piazza, Mechelli, Prince, & Butterworth, 2006; Revkin, Piazza, Izard, Cohen, & Dehaene, 2008) based on the *Objects Tracking System* (OTS; e.g., Atkinson, Campbell, & Francis, 1976; Trick & Pylyshyn, 1994).

Subitizing has been established in preverbal human infants (e.g., Xu, 2003) and in a variety of non-human species, including monkeys (e.g., Nieder & Miller, 2004; Phillips & Santos, 2007), rats (Davids & Memmott, 1983), parrots (Pepperberg, 1987) and cats (Thompson, Mayers, Robertson, & Patterson, 1970).

Various studies demonstrated that subitizing is an important factor in arithmetic development (Landerl, Bevan, & Butterworth, 2004; Penner-Wilger, Fast, LeFevre, Smith-Chant, Skwarchuk, & Kamawar , 2007).

DIFFERENCES IN ARITHMETIC PROFICIENCY

Differences in arithmetic proficiency between and within individuals are normal. Teachers are expected to cope with learning differences and to adjust their teaching style to the needs of all students. However in some cases these differences appear to be so severe or resistant that they can be considered as characteristics of ‘problems’ or even ‘disorders’.

The ICF-CY (The International Classification of Functioning, Disability and health for Children and Youth (ICF-CY; World Health organization, 2001) provides a universal language and framework among health professionals to facilitate the discussion about the impact (on activities and participation) of atypical arithmetic development (low achievement and learning disorders) in children and youth populations.

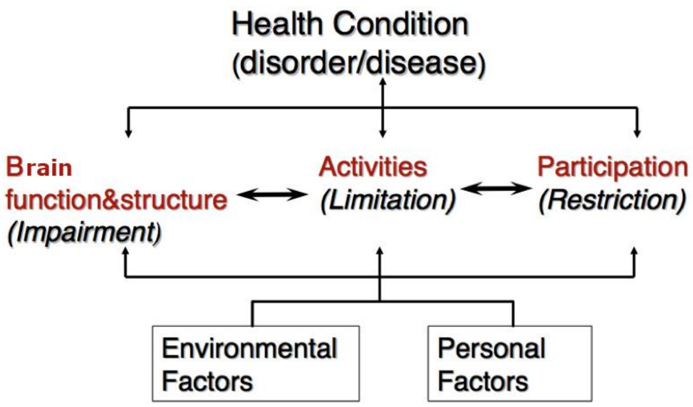


Figure 3. International Classification of Functioning, Disabilities, and Health (ICF). (World Health Organisation, 2001).

Currently **the DSM-5** (APA, 2013), reports a 7% prevalence of mathematical learning disorders in the school-age population. However, prevalence depends on the country of study because of different cut off scores (Barbaresi Katusic, Colligan, Weaver, & Jacobson 2005; Dowker, 2005; Shalev, Manor, & Gross-Tsur, 2005). Two subtypes have been documented. There is actually evidence for at least a procedural and a semantic memory subtype (Pieters et al., 2014; Geary, 1993; 2004; Robinson et al., 2002). The ***procedural subtype*** would be due to executive dysfunction and characterised by a developmental delay in the acquisition of counting and counting procedures used to solve simple arithmetic problems. The ***semantic memory subtype*** would be due to verbal memory dysfunction and is characterised by errors in retrieving arithmetic facts (Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006). However, not all studies have found different profiling for these groups (Landerl et al., 2004; Rousselle & Noel, 2007). Incongruence between researchers is ongoing in group profiling (Landerl et al., 2004; Rousselle & Noel, 2007).

Although there is no specific cut-off point for defining children as having a mathematical learning disorder, there is growing consensus among researchers to make a differentiation between two groups. Children with a score at or below percentile 10 for at least two consecutive academic years are described as having mathematical learning disorders (MLD), children having a score between percentile 11 and 25 are categorised as having low achievement in mathematics (Geary, 2011; Murphy, Mazzocco, Hanich, & Early, 2007; Moeller, Fischer, Vress, & Nuerk, 2012).

Mazzocco, Devlin and McKenney (2008) described **qualitatively different profiles** in fact retrieval performances between children with MLD and typically achieving children. The differences between children at the lower end of the continuum (Low Achievers) with a mild form of the disorder) and typically achieving children were **quantitative**.
Geary et al. (2007) revealed that children with MLD had severe cognition deficits in maths and underlying deficits in working memory and processing speed. The low achievers had **more subtle deficits in a few maths's domains**.

LANGUAGE

In recent years, the value of including language as a measure has been stressed in the prediction of numeracy development (Carey, 2004; Kleemans, Segers, & Verhoeven, 2011; LeFevre, Fast, Skwarchuk, Smith-Chant, Bisanz, Kamawar, & Penner- Wilger, 2010; Purpura, Hume, Sims, & Loningann, 2011; Romano, Babchishin, Pagani, & Kohen, 2010; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007; Wiese, 2003).

Purpura et al. (2011) revealed on 3–to 5-year-old pre-schoolers that print knowledge and vocabulary accounted for a large amount of unique variance in the numeracy scores. Additionally, there is evidence that a larger nominal vocabulary can be helpful in learning number words (Negen & Sarnecka, 2012), with number words facilitating arithmetic reasoning (Cowan & Renton, 1996). Van Borsel (1998) even suggested that arithmetical problems are a specific kind of language difficulty. Moreover, favoring the relationship between language and arithmetic, some studies (Barner, Chow, & Yang, 2009; Negen & Sarnecka, 2012) revealed that general measures of language development also predicted number-word knowledge.

However there are also studies (e.g., Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003) with contradictory findings, not demonstrating a significant positive correlation between language an arithmetic proficiency, with Levine, Jordan and Huttenlocher (1992), as well as Canobi and Bethune (2008), demonstrating that children in kindergarten were better problem solvers without language (and the knowledge of number words).

Moreover, Vukovic and Lesaux (2013) revealed that language only predicted gains for data analysis and geometry. They suggested that language ability might not be involved in learning how to handle precise numerical quantities, but that early language experiences are important for later arithmetic development regardless of the language backgrounds. To conclude, the field of research is extensive but in many cases contradictory. According to some authors, language is the driving force to make sense of the abstract symbols inherent to arithmetic. Some studies (Lager, 2006; Lefevre et al, 2010; Vukovic, 2012) considered arithmetic difficulties as reflections of deficient linguistic processes.

To conclude, there is still no consensus on many topics concerning language.

ENHANCEMENT OF ARITHMETIC PROFICIENCY

Structured interventions are important for enhancing early arithmetic (e.g., Griffin, 2004; Kaufmann, Delazer, Pohl, Semenza, & Dowker, 2005; Krajewski, Nieding, & Schneider, 2008). These **interventions** can have far reaching consequences on various levels (Clements & Sarama, 2011). The main aim of different interventions is focused at the curricular level. Long-term effects are found with Building Blocks (Clements, Sarama, Spitler, Lange, & Wolfe, 2011), Big Math for Little Kids (Greenes, Ginzburg & Balfanz., 2004) and Mengen, Zählen, Zahlen (Krajewski, et al., 2008).

With the introduction of computers a number of **educational or serious "games"** have been introduced to support early numeracy in kindergartners.
Computerised interventions on the **number line** - that is inherent in approximating magnitudes - were conducted by Siegler and Ramani (2009). These authors found positive results for improving numerical representations by playing linear board games. In addition, several studies focused on learning to **count.** Fuchs and colleagues (Fuchs, Powell, Seethaler, Cirino, Fletcher, Fuchs, & Hamlett, 2010) observed the enhancement of kindergarteners' numerical abilities. Moreover, Pasnak and colleagues (Pasnak, Kidd, Gadzichowski, Gallington, Saracina, & Addison 2009) made it clear that **seriation and conservation** also contributed to enhancing early numeracy.

However, there are only a few programs designed for kindergartners at risk of developing mathematical difficulties. There are some studies on children from families with low-economic statuses making significant gains in early numeracy achievement due to remedial intervention (Baroody, Eiland, & Thompson, 2009; Dyson, Jordan, & Glutting, 2013; Fuchs, Geary, Compton, Fuchs, Schatschneider, Hamlett,.. Changas, 2013; Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012). There is, however, only a **limited number of studies on children with weak early numerosity skills in kindergarten** (Aunio, Hautamäki, & Van Luit, 2005; Kamii, Rummelsburg, & Kari, 2005; Kroesbergen, & Van Luit, 2003; Van de Rijt, & Van Luit, 1998, Van Luit, & Schopman, 2000). Furthermore, games in the classroom are perceived negatively by parents, teachers and policy-makers (Bourgonjon, Valcke, Soetaert, de Wever, & Schellens, 2011).

RESEARCH OBJECTIVES AND OUTLINE OF THIS DISSERTATION

Until now, the relationship between language and arithmetic learning has not been investigated in depth. Nevertheless, there are many reasons to study this relationship, as outlined in this general introduction. Besides language, we wanted tot know the impact of the intervention in low-performing children. Furthermore we were interested in the evolution of the number line.

The main goal of this doctoral research was to gain insight into the relationship between language and arithmetic learning in elementary school children, on a behavioral level, by means of different studies.

Firstly, we empirically investigated the value of language as predictor for arithmetic in grade 1 (chapter 2) and grade 2 (chapter 3) .

Secondly, the evolution of number sense was evaluated by number line estimations from kindergarten till grade 2 in chapter 4.

Finally, we investigated whether we could enhance arithmetic proficiency by a preventive computerized intervention. Therefore we empirically evaluated the effect of a short computerized comparing and counting intervention in chapter 5.

This resulted in the following chapters.

Chapter 2 Language in the prediction of arithmetic in kindergarten and grade 1.

Chapter 3 Kindergarten language predicts arithmetic accuracy, not speed.

Chapter 4 Number line estimation from kindergarten to grade 2: a longitudinal study.

Chapter 5 Enhancing young children's mathematical skills through non-intensive computerized kindergarten interventions: A randomized controlled study.

Finally, in *Chapter 6,* a summary of the most important findings is provided, limitations are discussed and implications for future research and practice are given.

The chapters in this dissertation correspond to individual manuscripts, which are published (chapters 2-4-5) or under editorial review (chapter 3). Therefore, partial overlap between the chapters is possible as each manuscript is self-containing.

REFERENCES

American Psychiatric Association [APA]. (2013). *Diagnostic and statistical manual of mental disorders (5th ed.)*. Arlington, VA: American Psychiatric Publishing.

Anderson, A., Anderson, J., & Thauberger, C. (2008). Mathematics learning and teaching in the early years. In O.N. Saracho & B. Spodek (Eds.), Contemporary perspectives on mathematics in early childhood education (pp. 95–132). Charlotte, NC: Information Age Publishing. http://dx.doi.org/10.5860/choice.46-1616

Aunola, K., Leskinen, E., Lerkkanen, M. -K., & Nurmi, J. -E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96(4),* 699-713. http://dx.doi.org/10.1037/0022-0663.96.4.699

Aunio, P., Hautamäki, J., & Van Luit, J. E. H. (2005). Mathematical thinking intervention programmes for kindergarten children with normal and low number sense. *European Journal of Special Needs Education, 22(2),* 131–146. http://dx.doi.org/10.1080/08856250500055578

Ansari, D., Lyons, I.M., Van Eitneren, L., & Xu, F. (2007). Linking visual attention and number processing in the brain: The role of the temporo-parietal junction in small and large symbolic and nonsymbolic number comparison. *Journal of Cognitive Neuroscience 19*, 1845–1853. http://dx.doi.org/10.1162/jocn.2007.19.11.1845

Ansari, D., Donlan, C., Thomas, M. S., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology, 85*, 50-62. http://dx.doi.org/10.1016/S0022-0965(03)00026-2

Atkinson, J., Campbell, F.W., & Francis, M.R. (1976). The magic number 4±0: a new look at visual numerosity judgements. *Perception 5*, 327–334. http://dx.doi.org/10.1068/p050327.

Barbaresi WJ, Katusic SK, Colligan RC, Weaver AL, Jacobsen SJ. (2005) . Math learning disorder: incidence in a population-based birth cohort, 1976-82, Rochester, Minn. *Ambulatory Pediatrics 5(5），* 281-9. http://dx.doi.org/10.1542/peds.2008-2098.

Barner, D., Chow, K., & Yang, S. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58*, 195-219. http://dx.doi.org/10.1016/j.cogpsych.2008.07.001

Baroody, A. J., Eiland, M., & Thompson, B. (2009). Fostering at-risk preschoolers' number sense. *Early Education and Development, 20,* 80–120. http://dx.doi.org/10.1080/10409280802206619

Bertelli, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers. *Developmental Psychology*, *46*, 545-551. http://dx.doi.org/10.1037/a0017887.

Bisanz, J., & **LeFevre**, J. (1992). Understanding elementary mathematics. In J. I. D. Campbell (Ed.), *The Nature and Origins of Mathematical Skills*, (pp. 113-136). Amsterdam: North-Holland Elsevier Science Publishers.

Blöte, A. W., Lieffering, L. M., & Ouwehand, K. (2006). The development of many-to-one counting in 4-year-old children. *Cognitive Development, 21,* 332-348. http://dx.doi.org/10.1016/j.cogdev.2005.10.002

Bourgonjon, J., Valcke, M., Soetaert R., de Wever, B., & Schellens T. (2011). Parental acceptance of digital-game based learning. *Computers & Education, 57,* 1434-1444. http://dx.doi.org/10.1016/j.compedu.2010.12.012

Briars, D., & Siegler, R. S. (1984). A featural analysis of children’s counting. *Developmental Psychology, 20*, 607-618. http://dx.doi.org/10.1037/0012-1649.20.4.607

Browder, D. M., Jimenez, B.A., Spooner, F., Saunders, A., Hudson, M., & Bethune, K. S. (2013). Early Numeracy Instruction for Students With Moderate and Severe Developmental Disabilities; *Research and Practice for Persons with Severe Disabilities, 37 (4),* 308-320. http://dx.doi.org/10.2511/027494813805327205

Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: From Brain to Education, *Science, 332,* 1049-1053. http://dx.doi.org/10.1126/science.1201536

Canobi, K. H., & Bethune, N. E. (2008). Number words in young children’s conceptual and procedural knowledge of addition. *Cognition, 108(3),* 675–686. http://dx.doi.org/10.1016/j.cognition.2008.05.011

Carey, S. (2004). Bootstrapping and the origins of concepts. *Daedalus, 133,* 59–68. http://dx.doi.org/10.1162/001152604772746701

Cirino, P. T. (2011). The interrelationships of mathematical precursors in kindergarten. *Journal of Experimental Child Psychology, 108(4),* 713-733. http://dx.doi.org/10.1016/j.jecp.2010.11.004

Clements, D. H., & Sarama, J. (2011). Early childhood mathematics intervention. *Science*, *333,* 968-970. http://dx.doi.org/10.1126/science.1204537

Clements, D. H., Sarama, J., Spitler, M. E., Lange, A. A., & Wolfe, C. B. (2011). Mathematics learned by young children in an intervention based on learning trajectories: A large-scale cluster randomized trial. *Journal for Research in Mathematics Education, 42,* 127-168. http://www.jstor.org/stable/10.5951/jresematheduc.42.2.0127

Cowan, R., & Renton M. (1996). Do they know what they are doing? Children's use of economic addition strategies and knowledge of commutativity. *Educational Psychology, 16,* 407-420 . http://dx.doi.org/10.1080/0144341960160405

Cutini, S., & Bonato, M., (2012) . Subitizing and visual short-term memory in human and non-human species: a common shared system? *Frontier Psychiatrist, 3,* 469. http://dx.doi.org/10.3389/fpsyg.2012.00469

Davids, H., & Memmott, H. (1983). Autocontingencies – rats count to 3 to predict safety from shock. *Animal Learning and Behavior, 11 (1),* 95-100. http://dx.doi.org/10.3758/BF03212314

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44,* 1-42. http://dx.doi.org/10.1016/0010- 0277(92)90049-N

Dehaene, S. (2001). Précis of the number sense. *Mind & Language, 16*, 16—36. http://dx.doi.org/10.1111/1468-0017.00154

Dehaene, S. (1995). Electrophysiological evidence for category-specific word processing in the normal human brain. NeuroReport, 6:2153--215. http://dx.doi.org/10.1097/00001756-199511000-00014

Dehaene, S, & Cohen, L (1995): Towards an anatomical and functional model of number processing. Math Cogn 1:83–120.

Demeyere, N., Lestou, V., & Humphreys G.W. (2010) Neuropsychological evidence for a dissociation in counting and subitizing. *Neurocase 1,:* 219–237. http://dx.doi.org/10.1080/13554790903405719.

De Smedt, B., Verschaffel, L., & Ghesquière, P. (2009). The predictive value of numerical magnitude comparison for individual differences in mathematics achievement. *Journal of Experimental Child Psychology, 103(4),* 469-479 http://dx.doi.org/10.1016/j.jecp.2009.01.010

Dowker, A. (2005). Individual differences in arithmetic. Implications for psychology, neuroscience and education. Hove, UK: Psychology Press. http://dx.doi.org/10.4324/9780203324899

Dowker, A. (2008). Individual Differences in Numerical Abilities in Preschoolers Developmental, *Science* Volume 11, Issue 5, pages 650–654, http://dx.doi.org/10.1111/j.1467-7687.2008.00713.x

Dyson, N. I., Jordan, N. C., & Glutting, J. (2013). A number sense intervention for low-income kindergartners at risk for mathematics difficulties. *Journal of Learning Disabilities, 46*, 166-181. http://dx.doi.org/10.1177/0022219411410233

Entwisle, D. R., Alexander, K. L., & Olson, L. S. (2005). First grade and educational attainment by age 22: A new story. *American Journal of Sociology, 110*, 1458–1502. http://dx.doi.org/10.1086/428444

Flemish Ministry of Education and Training. (2014). Special educational needs. from http://www.ond.vlaanderen.be/specifieke-onderwijsbehoeften/

Fuchs, L. S., Powell, S. R., Seethaler, P. M., Cirino, P. T., Fletcher, J. M., Fuchs, D., & Hamlett, C. L. (2010). The effects of strategic counting instruction, with and without deliberate practice, on number combination skill among students with mathematics difficulties. *Learning and Individual Differences, 20*, 89-100. http://dx.doi.org/10.1016/j.lindif.2009.09.003

Fuchs, L.S. , Geary, D.C., Compton, D.L., Fuchs,D., Schatschneider,C., Hamlett,C.L.,.. Changas, P. (2013). Effects of First-Grade Number Knowledge Tutoring With Contrasting Forms of PracticeJ Educ Psychol.; 105(1): 58–77. http://dx.doi.org/10.1037%2Fa0030127

Furman, T., & Rubinstein, O. (2012). Symbolic and non-symbolic numerical representation in adults with and without developmental dyscalculia. *Behavior Brain Functions, 8*, 55 . http://dx.doi.org/10.1186/1744-9081-8-55

Freeman, N. H., Antonucci, C., & Lewis, C. (2000). Representation of the cardinality principle: Early conception of error in a counterfactual test. *Cognition, 74(1)*, 71-89. http://dx.doi.org/S0010-0277(99)00064-5 %5Bpii%5D

Geary, D. C., Bailey, D. H., Littlefield, A., Wood, P., Hoard, M. K., & Nugent, L. (2009). First-grade predictors of mathematical learning disability: A latent class trajectory analysis. *Cognitive Development, 24*, 411-429 .http://dx.doi.org/10.1016/j.cogdev.2009.10 .001

Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological and genetic components. *Psychology Bulletin, 114(2)*, 345-362. http://dx.doi.org/10.1037/0033-2909.114.2.345

Geary, D.C. (2004). Mathematics and Learning Disabilities. *Journal of learning Disabilities 37, (1)* , 4-15. http://dx.doi.org/10.1177/00222194040370010201

Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development, 78,* 1343-1359. http://dx.doi.org/10.1111/j.1467-8624.2007.01069.x

Geary, D. C., Hoard, M. K., & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for mathematical disability. *Journal of Experimental Child Psychology, 74,* 213-239. http://dx.doi.org/10.1006/jecp.2000.2561

Geary, D. C. (2011). Consequences, characteristics, and causes of poor mathematics achievement and mathematical learning disabilities. *Journal of Developmental and Behavioral Pediatrics, 32,* 250-263. http://dx.doi.org/10.1097/DBP.0b013e318209edef

Gelman, R., & Galistel, C. R. (1978). The child’s understanding of number. Cambridge, MA: Harvard University Press. http://dx.doi.org/10.3102/0013189x008005016

Gelman, R., & Meck, E. (1983). Preschoolers' counting: Principles before skill. *Cognition, 13(3),* 343-359. http://dx.doi.org/10.1016/0010-0277(83)90014-8

Gersten, R., & Chard, D. (1999). Number sense: Rethinking arithmetic instruction for students with mathematical disabilities. *Journal of Special Education, 33(1*), 18. http://dx.doi.org/10.1177/002246699903300102

Gersten, R., Clarke, B., Jordan, N., C., Newman-Gonchar, R., Haymond, K., & Wilkins, C. (2012) Universal Screening in Mathematics for the Primary Grades: Beginnings of a Research Base. *Exceptional Children , Vol. 78, (4)* http://search.proquest.com/docview/1022655103?accountid=11077

Greenes, C., Ginsburg, H. P., & Balfanz, R. (2004). Big math for little kids. *Early Childhood Research Quarterly, 19,* 159-166. http://dx.doi.org/10.1016/j.ecresq.2004.01.010

Griffin, S. (2004). Building number sense with Number Worlds: A mathematics program for young children. *Early Childhood Research Quarterly, 19,* 173– 180. http://dx.doi.org/10.1016/j.ecresq.2004.01.012

Grégoire, J. (2005). Développement logique et compétences arithmétiques. Le modèle piagétien est-il toujours actuel ? In M. Crahay, L. Verschaffel, E. De Corte & J. Grégoire. Enseignement et apprentissage des mathématiques. (pp. 57-77). Brussels: De Boeck.

Grégoire, J., & Desoete, A. (2009). Mathematical Disabilities–An Underestimated Topic? *Journal of Psychoeducational Assessment, 27,* 171-174. http://dx.doi.org/10.1177/0734282908330577

Halberda, J. & Feigenson, L. (2008). Developmental change in the acuity of the "Number Sense": The approximate number system in 3-, 4-, 5-, 6-year-olds and adults. *Developmental Psychology, 44(5),* 1457-1465. http://dx.doi.org/10.1037/a0012682

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), Conceptual and procedural knowledge: The case of mathematics (pp. 1-27). Hillsdale, NJ: Lawrence Erlbaum Associates.

Holloway, I.D., & Ansari, D. (2009) Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's math achievement. *Journal of Experimental Child Psychology, 103,* 17-29. http://dx.doi.org/10.1016/j.jecp.2008.04.001.

Houssart, J. (2001). 'Counting difficulties at Key Stage two.' *Support for Learning, 16*, 1, 11-16. http://dx.doi.org/10.1111/1467-9604.00179

Johansson, B. S. (2005). Number-word sequence skill and arithmetic performance. *Scandinavian Journal of Psychology, 46,* 157-167. http://dx.doi.org/10.1111/j.1467-9450.2005.00445.x

Jordan, N.C., Kaplan, D., & Locuniak, M.N., (2007). Predicting first-grade math achievement from developmental number sense trajectories. *Learning disabilities research & practice 22,* 36–46. http://dx.doi.org/10.1111/j.1540-5826.2007.00229.x

Jordan, N.C. , Glutting, J., Dyson,N., Hassinger-Das, B., & Irwin, C. (2012). Building kindergartners' number sense: A randomized controlled study. *Journal of Educational Psychology, 104 (3),* 647-660. http://psycnet.apa.org/doi/10.1037/a0029018

Kahneman, D., Treisman, A., & Gibbs, B.J .(1992) The reviewing of object files - object-specific integration of information. *Cogn Psychol 24:* 175–219. http://dx.doi.org/10.1016/0010-0285(92)90007-O

Kamawar, D., Lefevre, J. A., Bisanz, J., Fast, L., Skwarchuk, S. L., Smith-Chant, B., & Penner- Wilger, M. (2010). Knowledge of counting principles: How relevant is order irrelevance? *Journal of Experimental Child Psychology, 105(1-2),* 138-145. http://dx.doi.org/ S0022- 0965(09)00162-3 %5Bpii%5D10.1016/j.jecp.2009.08.004

Kamii, C., Rummelsburg, J., & Kari, A. (2005). Teaching arithmetic to low-performing, low-SES first graders. *Journal of Mathematical Behavior, 24*, 39-50. http://dx.doi.org/10.1016/j.jmathb.2004.12.004

Kaufmann, L., Delazer, M., Pohl, R., Semenza, C., & Dowker, A. (2005). Effects of a specific numeracy intervention program in kindergarten children: a pilot study. *Educational Research and Evaluation, 11,* 405-431. http://dx.doi.org/10.1080/13803610500110497

Kleemans, T., Segers, E., & Verhoeven, L. (2011). De achterstand van kinderen met ESM op getalbegrip. *Van Horen Zeggen*, 52, 1, 10-13.

Koponen, T., Aunola, K., Ahonen, T., & Nurmi, J. -E. (2007). Cognitive predictors of single-digit and procedural calculation skills and their covariation with reading skill. Journal of Experimental Child Psychology, 97, 220–241. http://dx.doi.org/10.1016/j.jecp.2007.03.001

Krajewski, K., Nieding, G., & Schneider, W. (2008). Kurz-und Langfristige Effekte Mathematischer Frühförderung im Kindergarten durch das Programm ‚Mengen, Zählen, Zahlen'. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, 40,* 135-146. http://dx.doi.org/10.1026/0049- 8637.40.3.135

Kroesbergen, E.H., & Van Luit, J.E.H. (2003). Mathematics interventions for children with special educational needs. *Remedial and Special Education, 24,* 97-114. http://dx.doi.org/10.1177/07419325030240020501

Lager, C. A. (2006). Types of mathematics-language reading interactions that unnecessarily hinder algebra learning and assessment. *Reading Psychology, 27,* 165–204. http://dx.doi.org/10.1080/02702710600642475

Landerl, K., & Moll, K. (2010). Comorbidity of learning disorders: Prevalence and familial transmission. *Journal of Child Psychology and Psychiatry, 51,* 287-294. http://dx.doi.org/10.1111%2Fj.1469-7610.2009.02164.x

Landerl, K., Bevan, A., & Butterworth, B. (2004) Developmental Dyscalculia and basic numeral capacities: a study of 8-9-year-old-students. *Cognition, 93(2004),* 99-125. http://dx.doi.org/10.1016/j.cognition.2003.11.004

Le Fevre, J.A., Smith-Chant, B. L., Fast, L., Skwarchuk, S.L., Sargla, E., Arnup, J. S., … Kamawar, D. (2006). What counts as knowing? The development of conceptual and procedural knowledge of counting from kindergarten through grade 2. *Journal of Experimental Child Psychology, 93*, 285-303. http://dx.doi.org/10.1016/j.jecp.2005.11.002

LeFevre, J.A.., Bisanz, J., Skwarchuk, S.-L., Smith-Chant, B., Fast, L. , Shanahan T., … Watchorn R. (2008). Conceptual Knowledge of Counting: How Relevant is Order Irrelevance? In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), Proceedings of the 30th Annual Conference of the Cognitive Science Society (pp. 1356-1362). Austin, TX: Cognitive Science Society.

LeFevre, J., Fast, L., Skwarchuk, S. L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner- Wilger, M. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development, 81 (6),* 1753-1767. http://dx.doi.org/10.1111/j.1467-8624.2010.01508.x

Levine, S. C., Jordan, N., & Huttenlocher, J. (1992). Development of calculation abilities in young children. *Journal of Experimental Child Psychology, 53 (1),* 72-103. http://dx.doi.org/10.1016/S0022-0965(05)80005-0

Lourenço, O., & Machado, A. (1996). In Defense of Piaget's Theory: A Reply to 10 Common Criticisms. *Psychological Review, 103,* 143-164. http://dx.doi.org/10.1037/0033-295X.103.1.143

Mazzocco, M.M., & Thompson, R.E.(2005). Kindergarten predictors of math learning disability. *Learning Disabilities Research & Practice, 20,* 142-155. http://dx.doi.org /10.1111/j.1540-5826.2005.00129x

Mazzocco, M. M., Devlin, K. T., & McKenney, S. L. (2008). Is it a fact? Timed arithmetic performance ofchildren with mathematical learning disabilities (MLD) varies as a function of how MLD is defined. *Developmental Neuropsychology, 33,* 318–344. http://dx.doi.org/10.1080/87565640801982403

Meck,W.H., & Church, R.M. (1983) A mode control model of counting and timing processes. *Journal of Experimental Psychology: Animal Behavior Processes 9,* 320–334. http://dx.doi.org /10.1037/0097-7403.9.3.320

Moeller, K., Fischer, U., Cress, U., & Nuerk, H. C. (2012). Diagnotics and interventions in dyscalculia: Current Issues and novel perspectives. In Z. Breznitz, O. Rubinstein, V. Molfese, & D.L. Molfese (Eds). Reading, writing, mathematics and the developing brain: Listening to many voices (pp233-276). Heidelberg, Germany. Springer

Morton, J. (2004) Understanding developmental disorders. A causal modelling approach. Oxford: Blackwell Publishing.

Morton J., & Frith, U.(1995).Causal modelling: A structural approach to developmental psychopathology. In D. Cicchetti & D.J. Cohen (Eds). Developmental psychopathology (Vol1: Theory and methods, pp 357-390). New York: Wiley

Murphy, M. M., Mazzocco, M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. *Journal of Learning Disabilities, 40,* 458-478. http://dx.doi.org/10.1177/00222194070400050901

Nan, Y., Knösche, T.R., & Luo, Y-J. (2006). Counting in everyday life: discrimination and enumeration. *Neuropsychologica, 44,* 1103-113. http://dx.doi.org/10.1016/j.neuropsychologia.2005.10.020

Negen, J., & Sarnecka, B.W. (2012). Number-concept acquisition and general vocabulary development. Child Development, 83, 2019-2027. http://dx.doi.org/10.1111/j.1467-8624.2012.01815.x

Nieder, A., & Miller, E.K. (2004). Analog numerical representations in rhesus monkeys: evidence for parallel processing. *Journal of cognitive neuroscience, 16 (5),* 889-901. http://dx.doi.org /10.1162/089892904970807

Nunes, T., Bryant, P., Evans, D., Bell, D., Gardner, A., Gardner, A., & Carraher, J. (2006). The contribution of logical reasoning to the learning of mathematics in primary school. *British Journal of Developmental Psychology, 00,* 1-21. http://dx.doi.org /10.1348/026151006X153127

Parsons, S., & Bynner, J. (2005). Does numeracy mattter more? National reserch and development center for Adult Literacy and Numeracy, Institute of Education, London,

Pasnak, R., Kidd, J. K., Gadzichowski, M. K., Gallington, D. A., Saracina, R. P., & Addison, K. T. (2009). Promoting early abstraction to promote early literacy and numeracy. *Journal of Applied Developmental Psychology, 30*, 239-249. http://dx.doi.org /10.1016/j.appdev.2008.12.006

Penner-Wilger M., Fast L., LeFevre J., Smith-Chant B. L., Skwarchuk S., Kamawar D., (2007). “The foundations of numeracy: subitizing, finger gnosia, and fine-motor ability,” in *Proceedings of the 29th Annual Cognitive Science Society* eds McNamara D. S., Trafton J. G., editors. (Austin, TX: Cognitive Science Society;) 1385–1390

Pepperberg, I.M. (1987). Evidence for conceptual quantitative abilities in the African Grey parrot: labeling of cardinal sets. *Ethology, 75,* 37-61. http://dx.doi.org/10.1111/j.1439-0310.1987.tb00641.x

Phillips, W., & Santos, L.R. (2007). Evidence for kind representations in the absence of language: Experiments with rhesus monkeys. *Cognition, 102*, 455-463. http://dx.doi.org/10.1016/j.cognition.2006.01.009

Piaget, J., & Szeminska, A. (1941). La genèse du nombre chez l’enfant.

Neuchâtel: Delanchaux et Niestlé.

Piazza, M., Mechelli, A., Price, C. J., & Butterworth, B. (2006). Exact and approximate judgements of visual and auditory numerosity: An fMRI study. *Brain Research, 1106,* 177-188. http://dx.doi.org/10.1016/j.brainres.2006.05.104

Pieters S., Roeyers H., Rosseel Y., Van Waelvelde H., & Desoete A. (2014). Identifying subtypes among children with developmental coordination disorder and mathematical learning disabilities using model-based clustering. *Journal of Learning Disabilities,47/1* . http://dx.doi.org /10.1177/0022219413491288

Potter, M. C., & Levy, E. I. (1968). Spatial enumeration without counting. *Child Development, 39 (1),* 265-272. http://www.jstor.org/stable/1127377

Purpura, D. J., Hume, L. E., Sims, D. M., & Loningan, C. J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology, 110*, 647-658. http://dx.doi.org /10.1016/j.jecp.2011.07.004

Reigosa-Crespo, V., Valdés-Sosa, M., Butterworth, B., Estévez, N., Rodréguez, M., Santos, E., Torres, P., Suàrez, R., & Lage, A. (2011), September 12). Basic Numerical Capacities and Prevalence of Developmental Dyscalculia: The Havana Survey. Developmental Psychology. Advance online publication. http://dx.doi.org /10.1037/a0025356

Resnick, L. B. (1989). Developing mathematical knowledge. *American Psychologist, 44(2),* 162- 169. http://dx.doi.org /10.1037/0003-066X.44.2.162

Revkin, S. K., Piazza, M., Izard, V., Cohen, L., & Dehaene, S. (2008). Does subitizing reflect numerical estimation? *Psychological Science, 19,* 607-614. http://dx.doi.org/10.1111/j.1467-9280.2008.02130.x

Robinson, C.S., Menchetti, B.M., & Torgesen, J.K. (2002). Toward a two-factor theory of one type of mathematics disabilities. *Learning Disabilities Research & Practice, 17(2),* 81-89. http://dx.doi.org /10.1111/1540-5826.00035

Romano, E., Babchishin, L. K., Pagani, L., & Kohen, D. E., (2010). "School readiness and later achievement: Replication and extension study using a nation-wide Canadian survey", *Developmental Psychology, 46,* 995-1007. http://dx.doi.org/10.1037/a0018880

Rousselle, L., & Noël, M-P. (2007). Basic numerical skills in children with mathematics learning disabilities: A comparison of symbolic vs non-symbolic number magnitude processing. *Cognition, 102,* 361-395. http://dx.doi.org/10.1016%2Fj.cognition.2006.01.005

Ruijssenaars, W., & Van Luit, H. (2007). Rekenen. In K. Verschueren, & H. Koomen (Eds), Handboek diagnostiek in de leerlingenbegeleiding (43-56). Antwerpen-Apeldoorn: Garant.

Sarnecka, B.W., & Carey, S. (2008). How counting represents number: What children must learn and when they learn it. *Cognition, 108*, 662-674. http://dx.doi.org /10.1016/j.cognition. 2008.05.007

Sarnecka, B.W., Kamenskaya, V.G., Yamana, Y., Ogura, T., & Yudovina, J.B. (2007). From grammatical number to exact numbers: Early meanings of "one," "two," and "three" in English, Russian, and Japanese. *Cognitive Psychology, 55,* 136-168. http://dx.doi.org/10.1016/ j.cogpsych.2006.09.001

Siegler, R., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75(2),* 428-444. http://dx.doi.org /10.1111/j.1467-8624.2004.00684.x

Siegler, R.S., & Opfer, J.E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science, 14,* 237-243. http://dx.doi.org/10.1111/1467-9280.02438.

Siegler, R. S., & Ramani, G. B. (2009). Playing linear number board games - but not circular ones - improves low-income kindergarteners' numerical understanding. *Journal of Educational Psychology, 101,* 545-560. http://dx.doi.org /10.1037/a0014239

Shalev, R.S., Manor, O., & Gross-Tsur, V. (2005). Developmental dyscalculia: a prospective six-year follow-up; *Developmental Medicine & Child Neurology, 47 (02)* , 121-125. http://dx.doi.org/10.1017/S0012162205000216

Sophian, C. (1988). Early developments in children's understanding of number: Inferences about numerosity and one-to-one correspondence. *Child Development, 59*, 1397. http://www.jstor.org/stable/1130502

Stock, P., Desoete, A. & Roeyers , H. (2007). Dyscalculie, een stoornis met vele gezichten. Een overzichtsbespreking van subtyperingen bij rekenstoornissen

Stock, P., Desoete, A., & Roeyers, H. (2009). Mastery of the counting principles in toddlers: A crucial step in the development of budding arithmetic abilities? *Learning and Individual Differences, 19(4),* 419-422. http://dx.doi.org/10.1016/j.lindif.2009.03.002

Thompson, R.F., Mayers, K.S., Robertson, R.T., & Patterson, C.J. (1970). Number coding in association cortex of the cat. *Science, 168*, 271-273. http://dx.doi.org/10.1126/science.168.3928.271

Trick L.M., & Pylyshyn, Z.W. (1994). Why are small and large numbers enumerated differently? A limitive capacity preattentive stage in vision .*Psychological Review, 10 (1),* 80-102. http://dx.doi.org /10.1037/0033-295X.101.1.80

Vetter, P., Butterworth, B., & Bahrami, B. (2011). A candidate for the attentional bottleneck: set-size specific modulation of the right TPJ during attentive enumeration. *Journal of Cognitive Neuroscience 23(3)*, 728-36. http://dx.doi.org/10.1162/jocn.2010.21472

Van Borsel, J. (1998) . Rekenproblemen linguïstisch bekeken. *Tijdschrift voor Logopedie en Audiologie, 28 (1),* 6-11.

Van de Rijt, B. A. M., & Van Luit, J. E. H. (1998). Effectiveness of the additional early mathematics program for teaching children early mathematics. *Instructional Science, 26,* 337-358. http://dx.doi.org /10.1023/A:1003180411209

Van Luit, J. E. H. (2002). Rekenen bij jonge kinderen. In A. J. J. W. Ruijssenaars & P. Ghesquière (Ed.). Dyslexie en dyscalculia: ernstige problemen in het leren lezen en rekenen. Recente ontwikkelingen in onderkenning en aanpak [Dyslexia and dyscalculia: Serious problems in learning to read and to calculate. Recent developments in detection and remediation]. Leuven: Acco.

Van Luit, J.E.H., & Schopman, A.M. (2000). Improving early numeracy of young children with special educational needs. *Remedial and Special Education, 21(1)*, 27-40. http://dx.doi.org/10.1177/074193250002100105

Vetter, P., Butterworth, B., & Bahrami, B .(2011). A candidate for the attentional bottleneck: Set-size specific modulation of right TPJ during attentive enumeration. *Journal of Cognitive Neuroscience 23,* 728–736. http://dx.doi.org/10.1162/jocn.2010.21472

Vukovic, & Lesaux (2013) The relationship between linguistic skills and arithmetic knowledge. *Learning and Individual Differences 23,* 87–91. http://dx.doi.org/10.1016/j.lindif.2012.10.007

Vukovic, R. K. (2012). Mathematics difficulty with and without reading difficulty: Findings and implications from a four-year longitudinal study. Exceptional Children, 78(3), 280-300. Retrieved from http://search.proquest.com/docview/926833523?accountid=11077

Wiese, H. (2003) Numbers language and the human mind Cambridge University Press Disability and Health for Children, Loghum.

Wilson, A. J., Revkin, S.K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of "The Number Race", an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions, 2* (20) , http://dx.doi.org/10.1186/1744-9081-2-20.

World Health Organisation. (2001). International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) Nederlandse vertaling. Houten, Nederland: Bohn Stafleu van Loghum

Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24,* 220-251. http://dx.doi.org/10.1016/00100285(92)90008-P

Xu, F. (2003). Numerosity discrimination in infants: Evidence for two systems of representations. *Cognition, 89* B15–B25. http://dx.doi.org/10.1016/S0010-0277(03)00050-7

II.
DIFFERENT STUDIES

Chapter 2

LANGUAGE IN THE PREDICTION OF ARITHMETIC IN KINDERGARTEN AND GRADE 1

Praet, M., Titeca, D., Ceulemans, A., & Desoete, A. (2013). Language in the prediction of arithmetic in kindergarten and grade 1. *Learning and Individual Differences*, *27*, 90-96. http://dx.doi.org 10.1016/j.lindif.2013.07.003

Abstract

A large body of evidence has proven the central influence of counting in the development of adequate arithmetic skills. Moreover a substantial amount of children with mathematical learning disorders in elementary school could correctly be diagnosed in kindergarten by combination of counting and magnitude estimation tasks. The present study expands previous findings, by adding language as predictor for arithmetic skills in kindergarten and grade 1. A sample of 63 children was tested in kindergarten on counting, logical thinking, estimation (number estimation, comparison and naming), language and arithmetic skills. These children were tested again on arithmetic in grade 1. Results reveal that language has a value added of 21.6% to number naming and counting as predictors for early arithmetic achievement in kindergarten. Moreover, language still predicts the importance of kindergarten language as predictor for arithmetic in grade 1 was stressed even when kindergarten arithmetic skills of children were taken into account. In addition, our findings suggest that number naming and comparison are better predictors for early arithmetic skills than number line estimation tasks in kindergarten.

Highlights

- Language explains 21.6% of the variance in arithmetic skills in kindergarten
- When we control for kindergarten arithmetic skills, language still predicts grade 1 arithmetic, with an explained unique variance of 4,9%
- Procedural and conceptual counting knowledge in kindergarten are significant predictors of arithmetic skills in kindergarten
- Number comparison and number naming skills predict significantly arithmetic skills in kindergarten

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) in 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 (Le Fevre 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 (Le Fevre 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 (Le Fevre 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 & Moore, 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, & Butterworth, 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, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Siegler & Booth, 2004). However, there is some discussion on this Number Line Estimation (NLE) paradigm (e.g. Cohen & Blanc- Goldammer, 2011; Defever, Sasanguie, Gebuis, & Reynvoet, 2011; Van Opstal, Gevers, De Moor, & Verguts, 2008) 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, Gebhardt, and Hartnegg (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 skills 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 et al., 2012; Purpura et al., 2011; Romano, Babchishin, Pagani, & Kohen, 2010; Sarnecka, Kamenskaya, Yamana, Ogura, & Ydovina, 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, 2009a; Negen & Sarnecka, 2012) reveal that general measures of language development predict number–word knowledge, although other studies (e.g., Ansari et al., 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-economic 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 68.21 months (*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

The TEDI-MATH has proven to be a well validated (Desoete, 2006; 2007a & b) and reliable instrument, values for Cronbach’s Alpha 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 till grade 1(Desoete & Grégoire, 2007) and on 240 children assessed in grade 1, 2 or 3 with TEDI-MATH and reassessed two years later with arithmetic tasks (Desoete, 2007). In addition the Flemish data were confirmed with similar data from the French speaking part of Belgium and France (Desoete, Roeyers, Schittekatte, & Grégoire, 2006).

Procedural knowledge of counting was assessed with subtest 1 of theTedi-Math (Grégoire, Noël, & Nieuwenhoven, 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 under- standing 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 et al. (2010) and Booth and Siegler (2006) a 0–100 interval was used. The task was computerized and included three exercise trials and 30 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 ms (as used in the study of Hannula et al. (2007) and Fischer et al. (2008)) and the child had to react within 5 s after the presentation. The test session consisted of 72 samples with a presentation time of 120 ms. The reaction time was reduced to 4000 ms. Reaction time and the number of correct responses were measured.

In the number 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 min 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 500 ms 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.

2.2.3. 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-4Nl (Kort, Schittekatte, & Compaan, 2008; Semel, Wiig, & Secord, 2008). The CELF-4Nl 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 (D'Hondt et al., 2008).

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) children completed the Kortrijk Arithmetic 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 3246 children.

2.2.6. Intelligence

Intelligence was assessed at T1 with the Wechsler Kindergarten and Primary Scale of Intelligence or the WPPSI-III-NL (Hendriksen & Hurks, 2009; Wechsler et al., 2002). 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 (T1) 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 regressions 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 T2), overall language and each of its components (assessed at T1), logical thinking (assessed at T1), the two types of counting (procedural counting and conceptual counting assessed at T1), and the three tasks for estimation (number line estimation, number comparison and number naming assessed at T1), we refer to Table 1.

Table 1 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).

Table 1

	TM (T1)	1	2	3	4	5	6	7	8	9	10	11
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.NumbComp	.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*	-
12Lg.structure	.601*	.458*	.927*	.375	.196	.194	-.341	.303	.300	.753*	.907*	.759*

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

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)

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, R2 = .249) for procedural counting knowledge (p = .005) and conceptual counting knowledge (p = .037; see Table 2).

The 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, R2 = .386) for number comparison (p = .009) and number naming (p = .011) but not for number line estimation (p = .199; see Table 2).

Table 2
Predictions with arithmetic skills in kindergarten (at T1) as outcome

	Unstandardised Coefficients	β	t	*p*
Counting				
Constant	-6.478		-1.928	.059
Proc. counting	1.428	.350	2.928	.005*
Conc. counting	.487	.255	2.135	.037*
Estimation				
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 ≤ .05 Note. Numb. = number, Proc. = procedural knowledge, Conc. = conceptual knowledge

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 regressions 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.

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 fourth 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).

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	<.001
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	<.001*
Logical thinking	.164	.102	.920	.362
Language variables				
Constant	-23.965		-5.413	<.001
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 ≤ .05 Note. 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		-.203	.840
T1 arithmetic skills	1.466	.266	1.985	.052
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. Numb. = number, Proc. = procedural knowledge, Conc. = conceptual knowledge

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 tap 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, 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 language. 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 significantly 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, Libenson, Cheung and Takasaki (2009b), Boonen, Kolkman, and Kroesbergen (2011), and Negen and Sarnecka (2012), language explained variance in arithmetic skills among young children. The core language index was 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.

4.1. 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) cannot 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 for example 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 line with Pieters et. al., (2013) 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.

4. Conclusion

The present study shows that 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.

References

Ansari, D., Donlan, C., Thomas, M. S.C., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology, 85*, 50–62. http://dx.doi.org/10.1016/S0022-0965(03)00026-2.

Ashcraft, M. H., & Moore, A.M. (2012). Cognitive processes of numerical estimation in children. *Journal of Experimental Child Psychology, 111*, 246–267. http://dx.doi.org/ 10.1016/j.jecp.2011.08.005.

Aunio, P., & Niemivirta, M. (2010). Predicting children's mathematical performance in grade one by early numeracy. *Learning and Individual Differences, 20,* 427–435. http://dx.doi.org/10.1016/j.lindif.2010.06.003.

Aunola, K., Leskinen, E., Lerkkanen, M. K., & Nurmi, J. E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96*, 699–713. http://dx.doi.org/10.1037/0022-0663.96.4.699.

Barner, D., Chow, K., & Yang, S. (2009a). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58* (2). http://dx.doi.org/10.1016/j.cogpsych.2008.07.001.

Barner, D., Libenson, A., Cheung, P., & Takasaki, M. (2009b). Cross-linguistic relations between quantifiers and numerals in language acquisition: Evidence from Japanese. *Journal of Experimental Child Psychology, 103*, 421–440. http://dx.doi.org/10.1016/ j.jecp.2008.12.001.

Baudonck, M., Debusschere, A., Dewulf, B., Samyn, F., Vercaemst, V., & Desoete, A. (2006). *Kortrijkse Rekentest Revisie (KRT-R).* Kortrijk:Revalidatiecentrum Overleie.

Berteletti, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers. *Developmental Psychology, 46*, 545–551. http://dx.doi.org/10.1037/ a0017887.

Boonen, A. J. H., Kolkman, M. E., & Kroesbergen, E. H. (2011). The relation between teachers' math talk and the acquisition of number sense within kindergarten classrooms. *Journal of School Psychology, 49*, 281–299. http://dx.doi.org/10.1016/j.jsp.2011.03.002.

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology, 42,* 189–201. http://dx.doi.org/10.1037/ 0012-1649.41.6.189.

Canobi, K. H., & Bethune, N. E. (2008). Number words in young children's conceptual and procedural knowledge of addition, subtraction and inversion. *Cognition, 108,* 675–686. http://dx.doi.org/10.1016/j.cognition.2008.05.011.

Cohen, D. J., & Blanc-Goldammer, D. (2011). Numerical bias in bounded and unbounded number line tasks. *Psychonomic Bulletin Reviews, 18*, 331–338. http://dx.doi.org/ 10.3758/sI3423-011-0059-z.

Cowan, R., & Renton, M. (1996). Do they know what they are doing? Children's use of eco- nomical addition strategies and knowledge of commutativity. *Educational Psychology, 16*, 407–420. http://dx.doi.org/ 10.1080/0144341960160405

Defever, E., Sasanguie, D., Gebuis, T., & Reynvoet, B. (2011). Children's representation of symbolic and non-symbolic magnitude examined with the priming paradigm. *Journal of Experimental Child Psychology, 109*, 174–186.

Dehaene, S., Izard, V., & Piazza, M. (2005). Control over non-numerical parameters in numerosity experiments. Unpublished manuscript (available at http://www.unicog. org/.../DocumentationDotsGeneration.doc).

Desoete, A., Ceulemans, A., De Weerdt, F., & Pieters, S. (2012). Can we predict mathematical learning disabilities from symbolic and non-symbolic comparison tasks in kindergarten? *British Journal of Educational Psychology, 82*, 64–81. http://dx.doi.org/10.1348/ 2044-8279.002002.

Desoete, A., & Grégoire, J. (2007). Numerical competence in young children and in children with mathematics learning disabilities. *Learning and Individual Differences, 16*, 351–367. http://dx.doi.org/10.1016/j.lindif.2006.12.006.

Desoete, A., Praet, M., Titeca, D., & Ceulemans, A. (2013). Cognitive phenotype of mathemat- ical learning disabilities: What can we learn from siblings*? Research in Developmental Disabilities, 34,* 404–412. http://dx.doi.org/10.1016/j.ridd.2012.08.022.

Desoete, A. (2006). Validiteitsonderzoek met de TEDI-MATH [Validity research on the TEDI-MATH]. *Diagnostiek-wijzer, 9*, 140-157.

Desoete, A. (2007a). Students with mathematical disabilities in Belgium: from definition, classification and assessment to STICORDI devices. (pp. 181-222). In T.E. Scruggs & M.A. Mastropieri (Eds.), Advances in Learning and Behavioral Disabilities, Vol. 20. International Perspectives Amsterdam & Oxford: Elsevier Press.

Desoete, A. (2007b). De TEDI-MATH. De plaats van de Tedi-Math in de diagnostiek van dyscalculie in Vlaanderen. [The value of the Tedi-Math in the assessment of mathematical learning disabilities in Flanders]. Caleidoscoop, 19 (6), 6-19.

Desoete, A., Roeyers, H., Schittekatte, M., & Grégoire, J. (2006). Dyscalculie-gevoelige kennis en vaardigheden in het basisonderwijs in Vlaanderen, Wallonië en Frankrijk. [Dyscalculia-sensitive knowledge and skills in elementary education in the Flemish and French speaking part of Belgium and in France]. Pedagogische Studieën, 83, 105- 121

D'Hondt, M., Desoete, A., Schittekatte, M., Kort, W., Compaan, E., Neyt, F., Polfiet, M., & Surdiacourt, S. (2008). De CELF-4-NL: een opvolger voor de TvK? Signaal, 65, 4-16.

Dickerson Mayes, S., Calhoun, S. L., Bixler, E. O., & Zimmerman, D. N. (2009). IQ and neuropsychological predictors of academic achievement. *Learning and Individual Differences, 19,* 238–241. http://dx.doi.org/10.1016/j.lindif.2008.09.001

Dowker, A.D. (2005). *Individual differences in arithmetic. Implications for psychology, neuroscience and education*. New York: Psychology Press.

Fischer, B., Gebhardt, C., & Hartnegg, K. (2008). Subitizing and visual counting in children with problems acquiring basic arithmetic skills. *Optometry and Vision Development, 39,* 24–29 (Retrieved from http://www.covd.org/Portals/0/24-29SubitizingVisualCounting. pdf).

Fuson, C. K. (Ed.). (1988). Children's counting and concepts of number. New York: Springer-Verlag.

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology, 47,* 1539–1552. http://dx.doi.org/ 10.1037/a0025510.

Geary, D. C., Hoard, M. K., Nugent, L., & Byrd-Craven, J. (2008). Development of number line representations in children with mathematical learning disability. *Developmental Neuropsychology, 33*, 277–299. http://dx.doi.org/10.1080/87565640901982361.

Grégoire, J. (2005). Développement logique et compétences arithmétiques. Le modèle piagétien est-il toujours actuel? [Logical development and arithmetical skills. Is the Piagetian model still correct?] In M. Crahay, L. Verschaffel, E. De Corte, & J. Grégoire (Eds.), Enseignement et apprentissage des mathématiques (pp. 57–77). Bruxelles: De Boeck.

Grégoire, J., Noël, M., & Nieuwenhoven, Van (2004). *Tedi-Math*. Antwerpen: Harcourt.

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the "number sense": The approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology, 44*, 1457–1465. http://dx.doi.org/10.1037/a0012682.

Halberda, J., Mazzocco, M. M. M., & Feigenson, L. (2008). Individual differences in non-verbal number acuity correlate with maths achievement. *Nature, 455,* 665–668. http://dx.doi.org/10.1038/nature07246.

Hannula, M. M., Räsänen, P., & Lehtinen, E. (2007). Development of counting skills: Role on numerosity and subitizing-based enumeration. *Mathematical Thinking, 9,* 51–57. http://dx.doi.org/10.1080/10986060709336605.

Heim, S., Amunts, K., Drai, D., Eickhoff, S. B., Hautvast, S., & Grodzinksy, Y. (2012). The language-number interface in the brain: A complex parametric study of quanti- fiers and quantities. *Frontiers in Evolutionary Neuroscience, 4.* http://dx.doi.org/ 10.3389/fnevo.2012.00004 (Article 4, 12 pp.).

Hendriksen, J., & Hurks, P. (2009). *WPSSI-III-NL Wechsler Preschool and Primary Scale of Intelligence.*

Holloway, I. D., & Ansari, D. (2009). Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's mathematics achieve- ment. *Journal of Experimental Child Psychology, 103*, 17–29. http://dx.doi.org/10.1016/ j.jecp.2008.04.001.

Inglis, M., Attridge, N., Batchelor, S., & Gilmore, C. (2011). Non-verbal number acuity cor- relates with symbolic mathematics achievement: But only in children. *Psychonomic Bulletin Review, 18*, 1222–1229. http://dx.doi.org/10.3758/s13423-011-0154-1.

Kort, W., Schittekatte, M., & Compaan, E. (2008). *CELF-4-NL Test voor diagnose en evaluatie van taalproblemen. Handleiding.* Amsterdam: Pearson.

Kroesbergen, E. H., Van Luit, J. E. H., & Aunio, P. (2012). Mathematical and cognitive predictors of the development of mathematics. *British Journal of Educational Psychology, 82*, 24–27. http://dx.doi.org/10.1111/j2044-8279.2012.02065.x.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8–9-year-old students. *Cognition*, *93*, 99–125. http://dx.doi.org/10.1016/j.cognition.2003.11.004.

Le Corre, M., Van de Walle, G., Brannon, E. M., & Carey, S. (2006). Re-visiting the competence/performance debate in the acquisition of the counting principles. *Cognitive Psychology, 52*, 130–169. http://dx.doi.org/10.1016/j.cogpsych.2005.07.002.

Le Fevre, J. -A., Smith-Chant, B.L., Fast, L., Skwarchuk, S. -L., Sargla, E., Arnup, J. S., et al. (2006). What counts as knowing? The development of conceptual and procedural knowledge of counting from kindergarten through grade 2. *Journal of Experimental Child Psychology, 93*, 285–303. http://dx.doi.org/10.1016/j.cognition.2003.11.004.

Levine, S.C., Jordan, N. C., & Huttenlocher, J. (1992). Development of calculation abilities in young children. *Journal of Experimental Child Psychology, 53*, 72–103. http://dx.doi.org/10.1016/j.cognition.2008.05.011.

Lourenço, O., & Machado, A. (1996). In defense of Piaget's theory: A reply to 10 common criticisms. *Psychological Review, 103*, 143–164. http://dx.doi.org/ 10.1037/0033-295X.103.1.143

Maloney, E. A., Risko, E. F., Ansari, D., & Fugelsang, J. (2010). Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition*, *114*, 293–297.

Negen, J., & Sarnecka, B. W. (2012). Number-concept acquisition and general vocabulary de- velopment. *Child Development.* http://dx.doi.org/10.1111/j.1467-8624.2012.01815.x.

Nunes, T., Bryant, P., Evans, D., Bell, D., Gardner, A., Gardner, A., et al. (2006). The contribution of logical reasoning to the learning of mathematics in primary school. *British Journal of Developmental Psychology, 00,* 1–21. http://dx.doi.org/10.1348/026151006X153127.

Piaget, J. (1965). The child's conception of number. New York: Norton.

Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., et al. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition, 116,* 33–41. http://dx.doi.org/ 10.1016/j.cognition.2010.03.012.

Pieters, S., Roeyers, H., Rosseel, Y., Van Waelvelde, H., & Desoete, A. (2013). Identifying subtypes among children with developmental coordination disorder and mathe- matical learning disabilities, using model-based clustering. *Journal of learning disabilities,11.* http://dx.doi.org/10.1177/0022219413491288.

Price, G. R., Palmer, D., Battista, C., & Ansari, D. (2012). Nonsymbolic numerical magnitude comparison: Reliability and validity of different task variants and outcome measures, and their relationship to arithmetic achievement in adults. *Acta Psychologica, 140*, 50–57. http://dx.doi.org/10.1016/j.actpsy.2012.02.008.

Purpura, D. J., Hume, L. E., Sims, D. C., & Lonigan, C. J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology, 110*, 647–658. http://dx.doi.org/10.1016/j.jecp.2011.07.004.

Romano, E., Babchishin, L., Pagani, L. S., & Kohen, D. (2010). School readiness and later achievement: Replication and extension using a nationwide Canadian survey. *Developmental Psychology, 46*, 995–1007. http://dx.doi.org/10.1037/a0018880

Sarnecka, B. W., Kamenskaya, V. G., Yamana, Y., Ogura, T., & Ydovina, Y. B. (2007). From grammatical number to exact numbers: Early meanings of one, two and three in English, Russian and Japanese. *Cognitive Psychology, 55*, 136–168. http://dx.doi.org/10.1016/ j.cogpsych.2006.09.001.

Semel, E., Wiig, E. H., & Secord, W. A. (2008). *CELF 4 Nl Clinical Evaluation of Language Fundamentals.* Amsterdam: Pearson.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75,* 428–444. http://dx.doi.org/10.1111/j.1467-8624.2004.00684.x.

Stock, P., & Desoete, A. (2009). Screening for mathematical disabilities in kindergarten. *Developmental Neurorehabilitation, 12,* 389–397. http://dx.doi.org/10.3109/17518420903046 752.

Stock, P., Desoete, A., & Roeyers, H. (2009). Mastery of the counting principles in toddlers: A crucial step in the development of budding arithmetic abilities? *Learning and Indi vidual Differences, 19,* 419–422. http://dx.doi.org/10.1016/j.lindif.2009.03.002.

Stock, P., Desoete, A., & Roeyers, H. (2010). Detecting children with arithmetic disabilities from kindergarten: Evidence from a three year longitudinal study on the role of preparatory arithmetic abilities. *Journal of Learning Disabilities, 43*, 250–268. http://dx.doi.org/10.1177/0022219409345011.

Storch, S. A., & Whitehurst, G. J. (2002). Oral language and code-related precursors to reading: Evidence from a longitudinal structural model. *Developmental Psychology, 38,* 934–947. http://dx.doi.org/ 10.1037/0012-1649.38.6.934

Van Opstal, F., Gevers, W., De Moor, W., & Verguts, T. (2008). Dissecting the symbolicdistance effect: Priming and comparison distance effects in numerical and non-numerical orders. *Psychometric Bulletin & Review, 15*, 419–425. http: //dx.doi.org/10.3758/PBR.15.2.419.

Vukovic,R.S.,&Lesaux,N.K.(2013).The relationship between linguistic skills and arithmetic knowledge. *Learning and Individual Differences, 23*, 87–91. http://dx.doi.org/10.10 16/j.lindif.2012.10.007.

Wechsler, D., Kort, W., Schittekatte, M., Bosmans, M., Compaan, E. L., Dekker, P. H., et al. (2002). *Wechsler Intelligence Scale for Children-III-NL*. Amsterdam, The Netherlands: Harcourt.

Wiese, H. (2003). Iconic and non-iconic stages in number development: The role of language. *Trends in Cognitive Science, 7,* 385–390. http://dx.doi.org/10.1016/S1364-6613(03) 00192-X

Chapter 3

KINDERGARTEN LANGUAGE PREDICTS ARITHMETIC ACCURACY, NOT SPEED. EVIDENCE FROM A LONGITUDINAL STUDY FOLLOWING-UP CHILDREN FROM KINDERGARTEN TILL GRADE 2.

Paper under review for publication

Abstract

This longitudinal study examined how language assessed in preschool (*n*=132) was related to children's early arithmetic skills in preschool and to their procedural calculation (or proficiency) and fact retrieval (or speed) abilities in grade 1 and 2. A group children was followed-up from preschool till grade 2.

The relationship between counting and arithmetic and the value of number line estimation on a 0-100 numberline was confirmed in this study. In addition, our data revealed that language had a unique contribution in explaining additional variance of early arithmetic skills in preschool. Moreover, there was unique value added to the prediction of procedural calculation in grade 1 and 2. Language in preschool added no explained variance of timed fact retrieval (speed) skills assessed in grade 2.

Highlights

- Significant relationship between counting, number estimation and arithmetic
- Language predicts arithmetic over and above counting and number estimation
- Language in preschool predicts calculation accuracy in grade 1 and 2
- Language in preschool does not predict fact retrieval skills in grade 2.
- Procedural counting knowledge in preschool predicts fact retrieval skills in grade 2.

1. Introduction

Numbers are not only important in a school context, but are inherent to many aspects of everyday life in all countries. Following a recipe requires an understanding of weights or measures and keeping track of your expenses requires you to perform basic arithmetic operations and to calculate fractions during sales. Arithmetic is of central importance to modern society and becomes increasingly essential in many job profiles (Engberg & Wolniak, 2013; Jordan & Levine, 2009). Research evidence illustrates the influence of arithmetic abilities on employment, promotion opportunities, and wages, over and above the influence of literacy (Geary, 2011b). Given the high social and individual cost associated with poorly developed arithmetic skills (Geary, 2011b), it is essential to gain insight into the processes underlying typical and atypical arithmetic development.

The field of research on *typical arithmetic development* is extensive (Bull & Johnston, 1997; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Geary, 1993; Jordan, Kaplan, Olah, & Locuniak, 2006; Jordan, Wylie, & Mulhern, 2010). However the interaction between the driving forces behind arithmetic is contradictory and it remains unclear 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), and number estimation (Ashcraft & More, 2012; Geary, 2011; Halberda, Mazzocco, & Feigenson, 2008).

In addition, the field of the study on the *atypical arithmetic development* is equally extensive but in many cases also contradictory. Based on recent studies, the prevalence of specific Learning Disorders in Mathematics in the general school-aged population varies between 2.27% and 14% depending on the country of the study and the diagnostic criteria used (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Desoete, Roeyers, & De Clercq, 2004; Dowker, 2005; Geary, 2011b; Shalev, Manor, & Gross-Tsur, 2005). According to the DSM-5 (APA, 2013), specific learning disorders in mathematics can manifest themselves on several domains. The first domain is already present before formal schooling (Dehaene, 2001). As such, *number estimation* as measure for number sense is part of the preschool early numerical competencies. The other domains reflect abilities acquired through formal schooling. The second domain, *Procedural calculation,* is needed when solving arithmetic problems, converting numerical information into arithmetical equations and algorithms (Dowker, 2005). The computational procedures are necessary in understanding the base-10 system and to solve more complex arithmetic problems (Geary, 2000). By executing arithmetic problems repetitively, basic number facts are retained in long-term memory and 'automatically' retrieved if needed, termed as *number fact retrieval* (Dowker, 2005). Elementary school children are expected, with sufficient practice, to memorize most basic arithmetic facts (Geary, 2000). Problems with number fact retrieval and calculation fit in the postulation of two subtypes of specific learning disorders in mathematics which has been made by several authors: a semantic memory subtype, characterized by problems in number fact retrieval and automatization (Geary, 2004; Mazzocco, Devlin, & McKenney, 2008; Pieters, Roeyers, Rosseel, Van Waelvelde, & Desoete, 2013; Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006) and a procedural subtype, characterized by frequent errors in the execution of procedures, the use of developmentally immature procedures to solve simple mathematical problems, a poor understanding of procedural concepts and problems with the sequencing of multiple steps within procedures (Geary & Hoard, 2005; Pieters et al., 2013). The awareness of the severe and long-term consequences associated with learning disorders in mathematics has stimulated research on early predictors and risk factors (Powell & Fuchs, 2012) to improve early identification and intervention (e.g., Coleman, Buysse, & Neitzel, 2006; Fuchs et al., 2007; Gersten, Jordan, & Flojo, 2005; Pasnak, Cooke, & Hendricks, 2006; Passolunghi & Lanfranchi, 2012).

The importance of preschool in the development of numeracy is not ignorable. Aunola, Leskinen, Lerkkanen, and Nurmil (2004) revealed that when children have high levels of numeracy in preschool, their numeracy even increases between preschool 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 if both 'calculation' (or procedural accuracy) and 'fact retrieval' (or speed) in arithmetic dependent on language. In addition although the predictive value of counting (e.g., Aunola et al., 2004, LeFevre et al., 2006) and estimation (e.g., Siegler & Booth, 2004; Geary et al., 2008) for later arithmetic performance in typically developing children (Praet et al., 2013) and children with learning disorders in mathematics (LeFevre et al., 2006; Geary et al., 2008) have clearly been demonstrated before, surprisingly few studies have been conducted to explore the combined effect of predictors on arithmetic with a longitudinal design. This study addresses this gap by investigating language in addition to other predictors of arithmetic skills in children. It is studied if preschool language adds to the prediction of arithmetic proficiency in grade 1 and 2 over and above counting and number estimation as preschool predictors.

Counting in kindergarten and early arithmetic

Aunola et al. (2004) and Johansson (2005) 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. In addition, Stock and colleagues (2009; 2010) and Gersten, Jordan and Flojo (2005) demonstrated that counting was one of the most important early markers for mathematical learning disabilities.

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).

Number estimation in kindergarten and early arithmetic

Number estimation is an important skill both in the classroom and in everyday life (Siegler & Booth, 2004). Several arguments support the claim that number estimation is associated with later arithmetic skills. There is behavioral evidence of difficulties resulting from a more imprecise number estimation in children with mathematical learning disabilities (MLD) compared to age-matched peers (e.g. Geary et al., 2009; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Mussolin, Mejias,

& Noel, 2010; Piazza et al., 2010; von Aster & Shalev, 2007). In addition, neuroimaging studies demonstrate that the intraparietal sulcus, the area in which representation of magnitudes is coded, is activated during arithmetical tasks(Ansari, 2008; Kadosh, Lammertyn, & Izard, 2008; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004) with MLD participants showing both structural and functional differences in this brain region (Molko et al., 2003; Mussolin et al., 2010; Price, Holloway, Rasanen, Vesterinen, & Ansari, 2007; Rotzer et al., 2008; Rubinsten & Henik, 2005).

A Number Line Estimation (NLE) paradigm, in which children have to estimate the position of a target number on a given number line, has often been used as an experimental measure of children's number estimation skills. The percentage absolute error (PAE) can be calculated as a measure of children's number estimation accuracy, following the formula of Siegler and Booth (2004):

PAE = (Estimate – Estimated Quantity Scale of Estimated)/100

For example, if a child was asked to estimate 50 on a 0-100 number line and placed the mark at the point on the line corresponding to 60, the PAE would be 10%, that is (60 - 50) / 100.

Previous research has shown an increase in estimation accuracy on the 0-100 line with age (from a PAE of 27% in kindergarten, to a PAE of 14% and 12% in grade 1 and 2 respectively; Berteletti, Lucangeli, & Zorzi, 2012). In addition studies revealed a developmental transition in the underlying representation of number line estimations, from a logarithmic representation (in kindergarten) to a more formally appropriate linear one, suggesting a changing representation with increasing formal schooling (Siegler & Booth, 2004; Siegler & Opfer, 2003). A logarithmic representation compresses the distance between magnitudes at the middle and upper ends of the interval (Siegler & Booth, 2004), whereas a linear representation provides an adequate reflection of the actual numbers. The linearity of judgments correlated positively with math achievement scores (Ashcraft & Moore, 2012; Siegler & Booth, 2004). In addition , children with MLD relied more on logarithmic placing as compared to typically achieving children (Geary et al., 2008).

Language in kindergarten and early arithmetic

Recently the value of including language as a measure has been stressed in the prediction of numeracy development (Romano, Babchishin, Pagani, & Kohen, 2010; Sarnecka et al., 2007; Wiese, 2003). In line with this finding, Praet and colleagues demonstrated in 63 children that language explained 21.6% of the variance in arithmetic skills in kindergarten (Praet, Titeca, Ceulemans, & Desoete, 2013). In addition, Purpura et al. (2011) revealed with a follow-up study on 69 3–to 5-year-old pre-schoolers that print knowledge and vocabulary accounted for a large amount of unique variance in the numeracy scores. Moreover, there is evidence that a larger nominal vocabulary can be helpful in learning number words (Negen & Sarnecka, 2012), with number words facilitating arithmetic reasoning (Cowan & Renton, 1996). Also, metacognitive executive functions (such as planning and verbal fluency) needed for arithmetic proficiency, revealed to correlate with the development of grammatical language (Ardila, 2013). Finally favoring the relationship between language and arithmetic, some studies (Barner, Chow, & Yang, 2009; Negen & Sarnecka, 2012) revealed that also general measures of language development predicted number-word knowledge.

However there are also studies (e.g., Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003) with contradictory findings, no demonstrating a significant positive correlation between language an arithmetic proficiency, with Levine, Jordan and Huttenlocher (1992), as well as Canobi and Bethune (2008), demonstrating that children in kindergarten were better problem solvers without language (and the knowledge of number words). Moreover, Vukovic and Lesaux (2013) revealed with a longitudinal study of 75 native English speakers and 92 language minority learners in the U.S. from grade 1 to grade 4 that language only predicted gains for data analysis and geometry. They suggested that language ability might not be involved in learning how to handle precise numerical quantities, but that early language experiences are important for later arithmetic development regardless of the language backgrounds. To conclude, the field of research is extensive but in many cases contradictory.

The current study

A large body of evidence supports the central influence of counting and number estimation in the development of adequate arithmetic skills. However, the additional predictive power of language over and above these predictors has empirically being poorly documented reflecting in contradictory findings. The present study expands previous findings, by adding language to counting and number estimation as predictors for arithmetic skills in kindergarten and grade 1 and 2.

In addition, since Vukovic and Lesaux (2013) revealed that language might not be involved in predicting gains for all arithmetic domains and Pieters et al. (2013) described a procedural and a semantic memory subtype in learning disorders, we will analyze if language provides additional longitudinal prediction for procedural calculation (calculation accuracy) and fact retrieval (speed) proficiency.

2. Method

Participants

In this study 132 children (48% girls) from the outskirts of Zele (Belgium) were tested in kindergarten (time T1), grade 1 (T2) and grade 2 (T3). 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).

Measures

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 subtest 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).

The TEDI-MATH has proven to be a well validated (Desoete, 2006; 2007a & b) and reliable instrument, values for Cronbach's Alpha 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 till grade 1(Desoete & Grégoire, 2007) and on 240 children assessed in grade 1, 2 or 3 with TEDI-MATH and reassessed two years later with arithmetic tasks (Desoete, 2007). In addition the Flemish data were confirmed with similar data from the French speaking part of Belgium and France (Desoete, Roeyers, Schittekatte, & Grégoire, 2006).

Number estimation skills

Number estimation was assessed with the Number Line Estimation (NLE) test at T1. Children were asked to put a single mark on a 0-100 number line to indicate the location of a number, 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.

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 or a measure of general language ability that quantifies children's overall language performance. In addition the CELF-IV results in a receptive language index, an expressive language index, a language content index and a language structure index. 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 (D'Hondt et al., 2008).

Arithmetic

To assess early arithmetic at T1 we used subtest 5 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 calculation proficiency. The KRT-R is an untimed standardized curriculum-based math test (e.g., 16 - 12 = … or 1 less than 8 is …). 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 the speed of 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.

Intelligence

Intelligence was assessed at T1 with the Wechsler Kindergarten 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).

Procedure

The study was approved by the ethical commission of Ghent University. Parents received an information letter and signed an informed consent before their participation. The first author, an experienced speech therapist tested all children on language and numeracy (during several short periods). Intelligence was tested under supervision of the second author. Children fell at ease during the testing. The solved the exercised with good concentration and since some of the test was on the I-pad, they even liked the testing. After completion of the test procedure, all the parents of the children received individual feedback on their children's results.

All children were tested individually at the end of the third year of preschool (T1) on counting, number estimation, language and intelligence. Their Dutch level was sufficient to understand the test instructions.

Six months later in Grade1 (= T2), all children were individually tested on the accuracy of their procedural calculation skills. They were too young to also study the speed differences at that moment.

In January (=T3) of grade 2 half of the children were tested again on the proficiency to solve procedural calculation skills (accuracy) and on their arithmetical fact retrieval skills (speed). Due to constraints in access to schools and the attending children, it was not feasible to collect data on all children at time period 3.

A hierarchical approach was used to investigate the degree to which language skills predicted early arithmetic in preschool (T1), calculation accuracy in grade 1 (T2) and grade 2 (T3) and fact retrieval speed (T3).

In step 1 counting variables (procedural counting and conceptual counting assessed at T1) and estimation variables (Percentage Absolute Error, PAE, on the 0-100 number line) were investigated as predictors of arithmetic (at T1, T2 and T3). In step 2 the core language index was entered into the model to examine the predictive power of language over and above counting and estimation variables as predictors.

3. Results

Bivariate relations among the constructs

The correlations between all measures (arithmetic measures, T1, T2 and T3), overall language and each of its components (assessed at T1), procedural and conceptual counting (assessed at T1), and number line estimation (PAE assessed at T1) are presented in Table 1.

The associations between all language pillars were substantial and statistically significant (r = .721 -.888, p <.001), therefor the core-index will be used to investigate the degree to which language predicts arithmetic abilities.

Early arithmetic in preschool (T1)

Hierarchical regression analyses were carried out to examine whether language predicts unique variance in early arithmetic skills in preschool. Step 1 involved the simultaneous inclusion of all the non-language variables (procedural counting, conceptual counting and number estimation) in the model. Procedural (p =.004) and conceptual (p <.001) counting knowledge and number estimation (p <.001) were significantly concurrently related to early arithmetic skills (F 3, 128) = 26.181, p < .001, R^2 = .386) in preschool.

Table 1:

	Arithmetic				Language	Non-language			Language components		
	TM	**KRT-R**	**KRT-R**	**TTR**	**Core index**	**Proc C.**	**Conc C.**	**Estimation**	**Receptive**	**Expressive**	**Content**
	(T1)	(T2)	(T3)	(T3)	(T1)	(T1)	(T1)	(T1)	(T1)	(T1)	(T1)
		Accuracy	Accuracy	Speed				-	-	-	-
	.462**	-	-		-	-	-	-	-	-	-
KRT(T3)	.677**	.679**	-	-	-	-	-	-	-	-	-
TTR(T3)	262	.197	.383**	-	-	-	-	-	-	-	-
L Core In	**.486****	**.458****	**.557****	**.234**	-	-	-	-	-	-	-
Proc.	.470**	.263**	.466**	.227	.312**	-	-	-	-	-	-
Con.	.453**	.250**	.362**	.054	.231**	.372*	-	-	-	-	-
Estimation	-.479**	-.344**	-.588**	-.291*	-.345**	-	-.233**	-	-	-	-
Recept. L	**.483****	**.463****	**.534****	**.330***	.726**	.245*	.222*	-.383**	-	-	-
Expressive L	**.555****	**.538****	**.624****	**.281***	.873**	.297*	.245**	-.435**	.731**	-	-
L Content	**.506****	**.421****	**.528****	**.146**	.743**	.287*	.234**	-.400**	.779**	.800**	-
L.Structuree	**.499****	**.456****	**.519****	**.324***	.918**	.250*	.204*	-.323**	.746**	.888**	.721*

Note. TM = Tedi-Math, KRT-R= Kortrijk Arithmetic test Revision; TTR= Tempotest Rekenen(fact retrieval); L Core index= language CoreIndex; Proc. Counting= Procedural Counting knowledge; Conc. Counting= conceptual counting knowledge; Estimation= error on nummer line task; Receptive L.= receptive language; Expressieve L= expressive language; L.content= language content index; L. Structure=language structure index, T1= kindergarten; T2= Start grade1, T3 start grade2 **p<.0005 *p<.003 (after Bonferoni adjustment)

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

	Unstandardised Coefficients	β	t	*p*
Early arithmetic				
Constant	-9.247		-2.414	.017
Procedural counting	.570	.182	2.342	.004*
Conceptual counting	.468	.254	3.512	.001**
Number estimation	-.151	-.257	-3.449	.001**
Language core index	.125	.278	3.825	.001**

$^*p \leq .05$ $^{**}p \leq .01$

Language was entered into the model in step 2 in order to examine the unique influence of language after controlling for counting and number estimation as predictors (see Table 2). This analysis showed a substantial delta-R-squared or unique amount of variance of 6.5%, indicating an additional predictive power of language for early arithmetic over and above counting and estimation (F (4, 128) = 25.433, p < .001, R^2 = .451). Moreover counting and number estimation remained significant predictors (see Table 2), meaning that language did not mediate the counting and estimation performances in preschool. Thus, we could predict 45.1% (R^2 = .451) of the variance of early arithmetic skills in preschool by looking at the counting, estimation and language proficiency of children.

Accuracy (procedural calculation) in grade 1 (T2)

Hierarchical regression analyses were carried out to examine whether language skills in preschool predicted unique variance in first grade calculation accuracy.

Step 1 involved the simultaneous inclusion of (procedural and conceptual) counting and number estimation assessed in preschool (T1).

This model was significant (F (3, 125) = 7.752, p < .001, R^2 = .160), with number estimation (p =.003) but not procedural (p =.350) or conceptual (p =.063) counting knowledge predicting unique variance in procedural calculation skills in grade 1. Thus, we could predict 16% (R^2 = .160) of the variance of calculation skills in grade 1 by looking at the preschool estimation skills of children.

In step 2, preschool language (core index) was added as predictor (see Table 3) into the model.

This model revealed a substantial delta-R-squared (10.2% of additional explained variance), indicating an additional predictive power of language for calculation skills in grade 1 over and above number estimation (F 4, 125) = 10.726, p < .001, R^2 = .262).

Thus, we could predict 26.2% (R^2 = .262) of the variance of calculation skills in grade 1 by looking at the preschool estimation and language skills of children. Moreover estimation remained a significant predictor (see Table 3), meaning that language was no mediator but added predictive power to the prediction of untimed arithmetic skills in grade 1.

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

	Unstandardised Coefficients	β	t	*p*
Constant	8.914		.945	*.347*
Procedural counting	.314	.047	.525	*.350*
Conceptual counting	.424	.117	1.374	*.172*
Number estimation	-.209	-.176	-1.993	*.049**
Language core index	.321	.349	4.082	*.001***

*p ≤ .05 **p ≤ .01

Accuracy (procedural calculation) and speed (fact retrieval) in grade 2

Half of the children were followed-up in grade 2. With regard to the calculation **accuracy data**, step 1 involved the inclusion of counting and estimation assessed in preschool into the model. This model was significant (F (3, 58) = 13.829, p < .001, R^2 = .430), with a significant association between arithmetic accuracy in grade 2 and number estimation (p <.001) but not with procedural counting knowledge (p =.087) or conceptual counting knowledge (p =.111).

Thus, we could predict 43% (R^2 = .430) of the variance of calculation skills in grade 2 by looking at the preschool estimation skills of children.

Step 2 involved the inclusion of the core language index. Adding language as predictor (see Table 4) revealed a substantial delta-R-squared (6.5% additional explained variance), indicating an additional predictive power of language for untimed arithmetic (calculation accuracy) in grade 2 over and above number estimation skills assessed in preschool (F 4, 58) = 2.922, p = .029).

Thus, we could predict 49.5% of the variance of calculation skills in grade 2 by looking at the preschool estimation and language skills of children.

With regard to the **speed or fact retrieval data**, a similar hierarchical regression analysis was conducted (see Table 4). After controlling for procedural counting (p =.014) and conceptual counting (p =.121) and number estimation (p =.176) assessed in preschool (F (3, 58) = 3.844, p = .014, R^2 = .173) in step 1, language was added (step 2). This analysis revealed about no additional or unique variance by language over and above procedural counting knowledge assessed in preschool (F 4, 58) = 2.922, p = .029, R^2 = .178).

Thus, we could especially predict fact retrieval skills in grade 2 by testing the counting knowledge of preschooler. About 17.6% of the variance of fact retrieval skills in grade 2 could be predicted by procedural counting in preschool. Language did not add to the prediction.

Table 4: *Kindergarten predictors with arithmetic (accuracy and speed) in grade 2 as outcome*

	Unstandardised Coefficients	β	t	*p*
Untimed arithmetic (accuracy) Constant	-6.376		-.725	.472
Procedural counting	1.128	.172	1.670	.101
Conceptual counting	.341	.114	1.415	.257
Number estimation	-.358	-.390	-3.900	.001**
Language core index	.290	.387	4.072	.001**
Timed arithmetic (speed) Constant	15.078		1.715	.092
Procedural counting	1.668	.348	2.478	.016*
Conceptual counting	-.509	-.225	-1.636	.108
Number estimation	-.115	-.168	-1.211	.231
Language core index	.038	.073	.549	.585

$^*p \leq .05$ $^{**}p \leq .01$

4. Discussion

The relationship between **counting** and arithmetic (Stock, Desoete, & Roeyers, 2009; 2010) was reconfirmed in this study. According to Dowker (2005) counting should be considered as a multifaceted construct, including both procedural and conceptual aspects. This study suggests that both constructs (procedural and conceptual counting knowledge) assessed in preschool were concurrently related to early arithmetic skills in preschool. Moreover, in line with Desoete et al. (2009) procedural counting knowledge (the ability to perform a counting task) in preschool was predictive for fact retrieval skills in grade 2.

Preschool children were also asked to put a single mark on the 0-100 number line to indicate the location of the number. The percentage absolute error (PAE) was calculated per child as a measure of children's estimation accuracy. The concurrent association between number **estimation** and early arithmetic skills in preschool was confirmed. In addition, the longitudinal prediction of number line estimation assessed in preschool for procedural calculation accuracy in grade 1 and 2 was demonstrated . However, the prediction for speed (fact retrieval) in grade 2 was not significant. To conclude, these findings underline the value of numberline estimation tasks in preschool, confirming the findings of earlier studies (e.g., Desoete et al., 2012; Desoete & Grégoire, 2007; Praet & Desoete, 2014) 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 preschool was investigated as cognitive predictor for arithmetic abilities. There was a longitudinal prediction of preschool language on top of the prediction of number estimation for arithmetic calculation accuracy in grade 1 and 2. In line with Barner et al. (2009), Boonen, Kolkman and Kroesbergen (2011), Hooper et al. (2010), Jordan et al. (2010) , Purpura et al. (2011) and Negen and Sarnecka (2012), language was an important arithmetic predictor. However, in line with Vukovic and Lesaux (2013) we also revealed that language only predicted gains for some and not all arithmetic domains. Our study revealed that language was only important to predict procedural calculation accuracy and not fact retrieval speed in arithmetic.

Fact retrieval speed could especially be predicted by the procedural counting knowledge of pre-schoolers.

Since previous studies on the relation between language and arithmetic abilities in children are scarce or inconclusive, the current study provides valuable insights on the processes underlying typical arithmetic development. However, 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 a larger group of participants is indicated. When doing so, a longitudinal approach in which children are followed up until the end of elementary school, can certainly provide more valuable insights in the typical arithmetic development. Moreover, given the typical heterogeneity in profiles of children with a specific learning disorders in mathematics (e.g., Pieters et al., 2013), it seems important to assess different arithmetic domains (certainly procedural calculation and fact retrievel, but perhaps also geometry and time related competences) in order to get a more comprehensive overview of their arithmetic skills.

To conclude, the findings from this study suggest that language should not be ignored as predictor for arithmetic. In addition arithmetic seems no unitary construct and different predictors can be found for arithmetic speed (timed fact retrieval tests) and accuracy (untimed calculation tests), with preschool language especially predicting calculation accuracy. Research might be interested to reveal whether language in interventions can enhance arithmetic skills in elementary school.

References

Ansari, D., Donlan, C., Thomas, M. S. C., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology, 85*, 50-62. 10.1016/S0022-0965(03)00026-2

American Psychiatric Association [APA]. (2013). *Diagnostic and statistical manual of mental disorders (5th ed.)*. Arlington, VA: American Psychiatric Publishing.

Ardila, A. (2013). Development of metacognitive and emotional executive functions in children. Applied Neuropsychology: Child. http://dx.doi.org/10.1080/21622965.2013,748388.

Aunola, K., Leskinen, E., Lerkkanen, M. K., & Nurmi, J. E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96*, 699-713. http://dx.doi.org/10.1037/0022-0663.96.4.699

Ashcraft, M. H., & Moore, A. M. (2012). Cognitive processes of numerical estimation in children. *Journal of Experimental Child Psychology, 111*, 246-267. http://dx.doi.org/10.1016/j.jecp.2011.08.005

Barbaresi, W. J., Katusic, S. K., Colligan, R. C., Weaver, A. L., & Jacobsen, S. J. (2005). Math learning disorder: Incidence in a population-based birth cohort, 1976-82, Rochester, Minn. *Ambulatory Pediatrics, 5,* 281-289. http://dx.doi.org/10.1367/a04-209r.1

Barner, D., Chow, K., & Yang, S. (2009). Finding one’s meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58***,** 195-219**.** http://dx.doi.org/10.1016/j.cogpsych.2008.07.001

Baudonck, M., Debusschere, A., Dewulf, B., Samyn, F., Vercaemst, V., & Desoete, A. (2006). *Kortrijkse Rekentest Revisie (KRT-R) [Kortrijk Arithmetic Test Revision]*. Kortrijk: Revalidatiecentrum Overleie.

Berteletti, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers. *Developmental Psychology, 46*, 545-551. http://dx.doi.org/10.1037/a0017887

Boonen, A. J. H., Kolkman, M. E., & Kroesbergen, E. H. (2011). The relation between teachers' math talk and the acquisition of number sense within kindergarten classrooms. *Journal of School Psychology, 49*, 281-299. http://dx.doi.org/10.1016/j.jsp.2011.03.002

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology, 42*, 189-201. http://dx.doi.org/10.1037/0012-1649.41.6.189

Brannon, E. M. (2005). What animals know about number. In J. I. D. Campbell (Ed.), *Handbook of mathematical cognition* (pp. 85-108). New York: Psychology Press.

Bull, R., & Johnston, R. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification and short term memory. *Journal of Experimental Child Psychology*, *65*, 1-24**.** http://dx.doi.org/10.1006/jecp.1996.2358

Coleman, M. R., Buysse, V., & Neitzel, J. (2006). *Recognition and response: An early intervening system for young children at-risk for learning disabilities. Research synthesis and recommendations.* University of North Carolina, North Carolina: FPG Child Development Institute.

Cowan, R., & Renton, M. (1996). Do they know what they are doing? Children's use of economical addition strategies and knowledge of commutativity. *Educational Psychology*, 16, 407–420.

Dehaene, S. (2001). Precis of the number sense. *Mind & Language, 16*, 16-36. http://dx.doi.org/10.1111/1468-0017.00154

Dehaene, S., Izard, V., & Piazza, M. (2005). Control over non-numerical parameters in numerosity experiments. Unpublished manuscript (available at http://www.unicog.org/…/DocumentationDotsGeneration.doc).

Dehaene, S., Spelke, E., Pinel, P., Stanescu, R., & Tsivkin, S. (1999) Sources of mathematical thinking: behavioral and brain-imaging evidence *Science*, 284,970-974. http://dx.doi.org/10.1126/science.284.5416.970

Desoete, A., & Grégoire, J. (2006). Numerical competence in young children and in children with mathematics learning disabilities. Learning and Individual Differences, 16, 351-367. http://dx.doi.org/10.1016/j.lindif.2006.12.006

Desoete, A., Ceulemans, A., De Weerdt, F., & Pieters, S. (2012). Can we predict mathematical learning disabilities from symbolic and non-symbolic comparison tasks in kindergarten? *British Journal of Educational Psychology, 82*, 64–81. http://dx.doi.org/10.1348/2044-8279.002002

Desoete, A., & Grégoire, J. (2007). Numerical competence in young children and in children with mathematics learning disabilities. *Learning and Individual Differences, 16*, 351-367. http://dx.doi.org/10.1016/j.lindif.2006.12.006

Desoete, A., Roeyers, H., & De Clercq, A. (2004). Children with mathematics learning disabilities in Belgium. *Journal of Learning Disabilities, 37*, 50-61. http://dx.doi.org/10.1177/00222194040370010601

Desoete, A., Stock, P., Schepens, A., Baeyens, D., & Roeyers, H. (2009). Classification, seriation, and counting in grades 1, 2, and 3 as two-year longitudinal predictors for low achieving in numerical facility and arithmetical achievement? *Journal of Psychoeducational Assessment, 27*, 252-264. http://dx.doi.org/10.1177/0734282908330588

De Vos, T. (1992). TempoTest Rekenen (TTR)(Arithmetic Number fact Test). Nijmegen : Berkhout

Dowker, A.D. (2005). *Individual differences in arithmetic. Implications for psychology, neuroscience and education.* New York: Psychology Press.

Dowker, A.D. (2008). Individual differences in numerical abilities in preschoolers. *Developmental Science, 11*, 50-654. http://dx.doi.org/10.1111/j.1467-7687.2008.00713.x

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani,L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*, 1428-1446. http://dx.doi.org/10.1037/0012-1649.43.6.1428

Ebersbach, M., Luwel, K., Frick, A., Onghena, P., & Verschaffel, L. (2008). The relationship between the shape of the mental number line and familiarity with numbers in 5-to 9-year old children: Evidence for a segmented linear model. *Journal of Experimental Child Psychology, 99*, 1-17. http://dx.doi.org/10.1016/jjecp.2007.08.006

Engberg, M. E., & Wolniak, G. C. (2013). College student pathways to the STEM disciplines. *Teachers College Record, 115*, 1-27.

Fuchs, L. S., Fuchs, D., Compton, D. L., Bryant, J. D., Hamlett, C. L., & Seethaler, P. M. (2007). Mathematics screening and progress monitoring at first grade: Implications for responsiveness to intervention. *Exceptional Children, 73*, 311-330.

Fischer, B., Gebhardt, C., & Hartnegg, K. (2008). Subitizing and visual counting in children with problems acquiring basic arithmetic skills. *Optometry and Vision Development, 39*, 24-29.

Geary, D. C. (1993). Mathematical Disabilities - Cognitive, neuropsychological and genetic components. *Psychological Bulletin, 114*, 345-362. http://dx.doi.org/10.1037//0033-2909.114.2.345

Geary, D. C. (2000). From infancy to adulthood: the development of numerical abilities. *European Child & Adolescent Psychiatry, 9*, 11-16. http://dx.doi.org/10.1007/s007870070004

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology, 88,* 121-151. http://dx.doi.org/10.1016/j.jecp.2004.03.002

Geary, D. C., Hoard, M. K., Nugent, L., & Byrd-Craven, J. (2008). Development of number line representations in children with mathematical learning disability. *Developmental Neuropsychology*, *33*, 277-299. http://dx.doi.org/10.1080/87565640901982361

Geary, D. C. (2011a). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology, 47*, 1539-1552. http://dx.doi.org/10.1037/a0025510

Geary, D. C. (2011b). Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics. *Journal of Developmental and Behavioral Pediatrics*, *32*, 250-263. http://dx.doi.org/10.1097/DBP.0b013e318209edef

Gersten, R., Clarke, B., Jordan, N. C., Newman-Gonchar, R., Haymond, K., & Wilkins, C. (2012). Universal screening in mathematics for the primary grades: Beginnings of a research base. *Exceptional Children, 78*, 423-445.

Gersten, R., Jordan, N. C., & Flojo, J. R. (2005). Early identification and interventions for students with mathematics difficulties. *Journal of Learning Disabilities, 38*, 293-304. http://dx.doi.org/10.1177/00222194050380040301

Ghesquière, P., & Ruyssenaers, A. 1994.Vlaamse normen voor studietoetsen rekenen en technisch lezen lager onderwijs (Flemish standards for study evaluation of mathematics and technical reading in primary schools) . Leuven Belgium: Catholic University of Leuven. Center for Educational and Professional Guidance.

Grégoire, J., Noël, M., & Van Nieuwenhoven (2004). *Tedi-Math.* Antwerpen: Harcourt.

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the “number sense”: The approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology*, *44*, 1457–1465. http://dx.doi.org/10.1037/a0012682

Halberda, J., Mazzocco, M. M. M., & Feigenson, L. (2008). Individual differences in non-verbal number acuity correlate with maths achievement. *Nature, 455*, 665-U662. http://dx.doi.org/10.1038/nature07246

Hannula, M. M., Räsänen, P., & Lehtinen, E. (2007). Development of counting skills: Role on numerosity and subitizing-based enumeration. *Mathematical Thinking, 9*, 51-57. http://dx.doi.org/10.1080/10986060709336605

Hendriksen ,J., & Hurks, P. (2009) WPPSI-III-NL | Wechsler Preschool and Primary Scale of Intelligence.

Holloway, I. D., & Ansari, D. (2009). Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's mathematics achievement. *Journal of Experimental Child Psychology, 103*, 17-29. http://dx.doi.org/10.1016/j.jecp.2008.04.001

Hooper, S., Roberts, J., Sideris, J. Burchinal, M., & Zeisel, S. (2010). Longitudinal predictors of reading and math trajectories through middle school from African American versus Caucasian students across two samples. *Development Psychology, 46*, 1018-1029. http://dx.doi.org/10.1037/a0018877

Inglis, M., Attridge, N., Batchelor, S, & Gilmore, C. (2011). Non-verbal number acuity correlates with symbolic mathematics achievement: But only in children. *Psychonomic Bulletin & Review, 18*, 1222–1229. http://dx.doi.org/ 10.3758/s13423-011-0154-1

Jordan, N., Kaplan, D., Olah, L., & Locuniak, M. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development, 77*, 153-175. http://dx.doi.org/10.1111/j.1467-8624.2006.00862.x

Jordan, N. C., & Levine, S. C. (2009). Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental Disabilities Research Reviews, 15*, 60-68. http://dx.doi.org/10.1002/ddrr.46

Jordan, J., Wylie, J., & Mulhern, G. (2010). Phonological awareness and mathematical difficulty: A longitudinal perspective. *Britisch Journal of Developmental Psychology, 28*, 89-107. http://dx.doi.org/ 10.1348/026151010X485197

Kort, W., Schittecatte, M., Dekker, P.H., Verhaeghe, P., Compaan, E.L., Bosmans, M.,& Vermeir,; G. (2005). WISC-III-NL Wechsler Intelligent scale for Children. David Wechsler. 3th Ed NL (pp 1-48). Amsterdam: Harcourt test Publishers/NIP Dienstencentrum

Kort, W., Schittekatte, M., & Compaan,E.,(2008) *CELF-4-NL Test voor diagnose en evaluatie van taalproblemen. Handleiding [Test for the evaluation of language problems. Manual]*. Amsterdam: Pearson.

Le Corre, M., Van de Walle, G., Brannon, E. M., & Carey, S. (2006). Re-visiting the competence/performance debate in the acquisition of the counting principles. *Cognitive Psychology, 52*, 130-169. http://dx.doi.org/ 10.1016/j.cogpsych.2005.07.002

LeFevre, J. A., Smith-Chant, B. L., Fast, L., Skwarchuk, S. L., Sargla, E., Arnup, J. S., . . . Kamawar, D. (2006). What counts as knowing? The development of conceptual and procedural knowledge of counting from kindergarten through Grade 2. *Journal of Experimental Child Psychology, 93*, 285-303. http://dx.doi.org/10.1016/j.jecp.2005.11.002

Maloney, E.A., Risko, E.F, Ansari, D., & Fugelsang, J. (2010). Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition, 114*, 293-297. http://dx.doi.org/10.1016/j.cognition.2009.09.013

Mazzocco, M. M. M., Devlin, K. T., & McKenney, S. J. (2008). Is it a fact? Timed arithmetic performance of children with Mathematical Learning Disabilities (MLD) varies as a function of how MLD is defined. *Developmental Neuropsychology, 33*, 318-344.http://dx.doi.org/10.1080/87565640801982403

Molko, N., Cachia, A., Riviere, D., Mangin, J. F., Bruandet, M., Le Bihan, D., . . . Dehaene, S. (2003). Functional and structural alterations of the intraparietal sulcus in a developmental dyscalculia of genetic origin. *Neuron, 40*, 847-858. http://dx.doi.org/10.1016/s0896-6273(03)00670-6

Mussolin, C., Mejias, S., & Noël, M. P. (2010). Symbolic and nonsymbolic number comparison in children with and without dyscalculia. *Cognition, 115*, 10-25. http://dx.doi.org/10.1016/j.cognition.2009.10.006

Negen, J., & Sarnecka, B.W. (2012). Number-Concept Acquisition and General Vocabulary Development, *Child Development, 83,* 2019-2027 http://dx.doi.org/ 10.1111/j.1467-8624.2012.01815.x

Pasnak, R., Cooke, W. D., & Hendricks, C. (2006). Enhancing academic performance by strengthening class-inclusion reasoning. *Journal of Psychology, 140*, 603-613. http://dx.doi.org/10.3200/jrlp.140.6.603-613

Passolunghi, M. C., & Lanfranchi, S. (2012). Domain-specific and domain-general precursors of mathematical achievement: A longitudinal study from kindergarten to first grade. *British Journal of Educational Psychology, 82*, 42-63. http://dx.doi.org/10.1111/j.2044-8279.2011.02039.x

Passolunghi, M.C., Vercelloni, B., & Schadeee H. (2007). The precursors of mathematics learning:working memory, Phonological Ability and numerical competence. *Cognitive development 22*, 165-184 http://dx.doi.org/ 10.1016/j.cogdev.2006.09.001

Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., . . . Zorzi, M. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition, 116*, 33-41. http://dx.doi.org/ 10.1016/j.cognition.2010.03.012

Pieters, S., Roeyers, H., Rosseel, Y., Van Waelvelde, H., & Desoete, A. (2013). Identifying subtypes among children with developmental coordination disorder and mathematical learning disabilities, using model-based clustering *Journal of Learning Disabilities*. http://dx.doi.org/10.1177/0022219413491288

Powell, S. R., & Fuchs, L. S. (2012). Early numerical competencies and students with mathematics difficulty. *Focus on Exceptional Children*, *44*, 1-16.

Praet, M., & Desoete, A. (2014). Number line estimation from kindergarten to grade 2. A longitudinal study. *Learning and instruction, 33*, 19-28. http://dx.doi.org/10.1016/j.learninstruc.2014.02.003.

Praet, M., Titeca, D., Ceulemans, A., & Desoete, A. (2013). Language in the prediction of arithmetics in kindergarten and grade 1. *Learning and Individual Differences, 27*, 90-96. http://dx.doi.org/10.1016/j.lindif.2013.07.003

Price, G. R., Palmer, D., Battista, C., & Ansari, D. (2012). Nonsymbolic numerical magnitude comparison : Reliability and validity of different task variants and outcome measures, and their relationship to arthmetic achievement in adults. *Acta Psychologica, 140*, 50-57. doi :10.1016/j.actpsy.2012.02.008

Purpura, D.J., Hume, L.E., Sims, D,C., & Lonigan, C.J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology, 110,* 647-658. http://dx.doi.org/10.1016/j.jecp.2011.07.004.

Romano, E., Babchishin, L. Pagani, L.S., & Kohen, D. (2010). School readiness and later achievement: Replication and extension using a nationwide Canadian survey. *Developmental Psychology*, *46*, 995-1007. http://dx.doi.org/10.1037/a0018880

Rotzer, S., Kucian, K., Martin, E., von Aster, M., Klaver, P., & Loenneker, T. (2008). Optimized voxel-based morphometry in children with developmental dyscalculia. *Neuroimage*, *39*, 417-422. http://dx.doi.org/10.1016/j.neuroimage.2007.08.045

Rubinsten, O., & Henik, A. (2005). Automatic activation of internal magnitudes: A study of developmental dyscalculia. *Neuropsychology, 19*, 641-648. http://dx.doi.org/10.1037/0894-4105.19.5.641

Sarnecka, B.W., & Carrey, S. (2008). How counting represents number: What children must learn and when they learn it. *Cognition, 108,* 662-674. http://dx.doi.org/10.1016/j.jecp.2009.02.007

Sarnecka, B.W., Kamenskaya, V.G., Yamana, Y., Ogura, T., & Ydovina, Y.B. (2007). From grammatical number to exact numbers: early meanings of one, two and three in English, Russian and Japanese, *Cognitive Psychology, 55*, 136-168. http://dx.doi.org/10.1016/j.cogpsych.2006.09.001.

Semel, E., Wiig, E. H., & Secord W.A.,(2008). *CELF 4 Nl Clinical Evaluation of language Fundamentals*. Amsterdam :Pearson.

Shalev, R. S., Manor, O., & Gross-Tsur, V. (2005). Developmental dyscalculia: a prospective six-year follow-up. *Developmental Medicine and Child Neurology, 47*, 121-125. http://dx.doi.org/10.1017/s0012162205000216

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75*, 428-444. http://dx.doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science, 14*, 237-243. http://dx.doi.org/10.1111/1467-9280.02438

Stock, P., & Desoete, A. (2009). Screening for mathematical disabilities in kindergarten. *Developmental Neurohabilitation, 12*, 389-397 http://dx.doi.org/10.3109/17518420903046752

Stock, P., Desoete, A., & Roeyers, H. (2009). Mastery of the counting principles in toddlers: A crucial step in the development of budding arithmetic abilities? *Learning and Individual Differences, 19,* 419-422. http://dx.doi.org/10.1016/j.lindif.2009.03.002.

Stock, P., Desoete, A., & Roeyers, H. (2010). Detecting children with arithmetic disabilities from kindergarten: Evidence from a three year longitudinal study on the role of preparatory arithmetic abilities. *Journal of Learning Disabilities*, *43*, 250-268. http://dx.doi.org/10.1177/0022219409345011.

Storch, S.A., & Whitehurst, G.J. (2002). Oral language and code-related precursors to reading: Evidence from a longitudinal structural model. *Developmental Psychology, 38,* 934-947. http://dx.doi.org/10.1037//0012-1649.38.6.934

von Aster, M. G., & Shalev, R. S. (2007). Number development and developmental dyscalculia. *Developmental Medicine and Child Neurology, 49,* 868-873. http://dx.doi.org/10.1111/j.1469-8749.2007.00868.x

Wechsler, D., Kort, W., Schittekatte, M., Bosmans, M., Compaan, E.L., Dekker, P.H., & Verhaeghe, P. (2002). *Wechsler Intelligence Scale for Children-III-Nl.* Amsterdam, The Netherlands: Harcourt.

Wilson, A. J., Revkin, S. K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of "the number race", an adaptive computer game for remediation of dyscalculia. *Behavioral Brain Function, 2*, 20. http://dx.doi.org/10.1186/1744-9081-2-20

White, S. L. J., & Szucs, D. (2012). Representational change and strategy use in children's number line estimation during the first years of primary school. *Behavioral and Brain Functions, 8*. http://dx.doi.org/10.1186/1744-9081-8-1

Wiese, H. (2003). Iconic and non-iconic stages in number development: the role of language. *Trends in Cognitive Science, 7*, 385-390. http://dx.doi.org/10.1016/S1364-6613(03)00192-X.

Chapter 4

NUMBER LINE ESTIMATION FROM KINDERGARTEN TO GRADE 2. A LONGITUDINAL STUDY.

Praet, M., & Desoete, A. (2014).
Learning and Instruction 01/2014 33:19–28.
http://dx.doi.org/10.1016/j.learninstruc.2014.02.003

Abstract

A bulk of evidence supports the association of number line estimations using Arabic digits and dots with maths learning. Surprisingly few studies have been conducted to explore the relationship between estimations using number words and mathematics. The present study expands previous findings by investigating estimations in three formats (Arabic digits, dots and numbers), adding language as a predictor and focusing on timed and untimed maths learning. A sample of 132 children was followed from kindergarten till grade 2. Results reveal variability in estimation accuracy and errors declining with age and instruction in all children. In addition, our findings suggest that language explains variation in kindergarten but not in evolution and, in particular, untimed maths achievement can be predicted by number line estimation. We will discuss the implications for assessment, prediction of maths learning and instruction.

1. Introduction

There has been extensive research on number line estimation (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Schneider et al., 2008; Slusser, Santiago, & Barth, 2013) and the relationship with mathematics. However, most of these studies have a cross-sectional design, using dots or Arabic numbers (e.g. Ashcraft & Moore, 2012; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Moeller, Pixner, Kaufmann, & Nuerk, 2009; Muldoon, Towse, Simms, Perra & Menzies Towse, 2013; Sasanguie, Göbel, Moll, Smets & Reynvoet, 2013) as stimuli for the estimations. In addition to estimations, the value of including language as predictor for mathematics has been stressed (Praet, Titeca, Ceulemans & Desoete, 2013; Sarnecka et al., 2007; Wiese, 2003). However, surprisingly few studies have been conducted to explore the combined effect of these predictors on maths learning. This study addresses this gap and has the unique scientific merit of focusing on age-related changes in children's numerical estimation accuracy and distribution using three different format types (stimuli as Arabic numerals, spoken number words, and dot patterns) at five measuring points (from kindergarten to grade 2), with children becoming more familiar with numbers up to 100 (learning to count in kindergarten, dealing with numbers from 0 to 20 in grade 1 and up to 100 in grade 2). This study also expands previous findings by investigating the prediction for timed and untimed maths learning. Insight about the detailed nature of underlying number representations can inform targeted assessment and might have educational implications for learning and instructional researchers and professionals addressing kindergarteners at risk of mathematical learning difficulties.

1.1. Numerical estimation and development

It is widely accepted that there is a gain in accuracy for number line judgments on a 0-100 interval with increased formal schooling. Additionally, research indicates a developmental transition from a logarithmic distribution of the representation of numbers from kindergarten to primary school (with children experiencing a larger distance between 2 and 3 than between 18 and 19) to a more linear function as the result of a better one-to-one correspondence between the value being judged and its estimate (Siegler & Booth, 2004; Siegler

& Opfer, 2003) The linearity of judgments is often positively correlated with maths learning (Ashcraft & Moore, 2012; Siegler & Booth, 2004).

In his triple code model Dehaene stated that number representation takes place in three different ways, with three different formats, located in three different brain regions (Dehaene, 1992, 1997, Dehaene & Cohen, 1995). Firstly, there is a (symbolic) visual system where numbers are encoded as strings of Arabic digits (e.g. ‘14’), which is needed for multidigit calculation and parity judgments. Secondly, there is a (symbolic) verbal system where numbers are represented as sequences of number words (e.g. ‘fourteen’), lexically, phonologically and syntactically. The third system uses (asymbolic) analogue magnitude codes as non-verbal semantic size and for distance relations (e.g. a collection of 14 dots).

Although evidence was found for a general, modality-independent representation across different kind of magnitudes; such as numbers, quantities of objects, lengths and durations (Barth, Kanwisher, & Spelke 2003; Huntley-Fenner & Cannon, 2000), some studies have found a relationship between symbolic tasks but not between non-symbolic number comparison skills and maths learning (e.g. De Smedt, Noel, Gilmore & Ansari, 2013; Holloway & Ansari, 2009; Mundy & Gilmore, 2009). Additionally, up until now, most studies focussed on non-symbolic magnitude representation, sometimes in combination with the symbolic representation with Arabic numbers (e.g. Ashcraft & Moore, 2012; Geary et al., 2008; Moeller et al., 2009; Muldoon et al., 2013; Sasanguie et al., 2013). On the basis of such data it is often unclear whether it is the Arabic number or number words processing that is important for maths learning. Finally, Sasanguie and colleagues (2013) suggested an association between estimation and a general curriculum-based maths test but not with a timed maths fluency test. Therefore, we ourselves might question whether the format used to test number estimation or maths learning affects on the observed relationships.

Over the past decades several researchers have studied the relationship between estimation and mathematics achievement. In a recent longitudinal study Muldoon and colleagues (2013) revealed that 5 year olds with less accurate internal representations of numbers, tested on 4 occasions at 3 months intervals, were disadvantaged on some early maths tasks compared to peers with better quality representations. These included such tasks as recognising number names and numerals, identifying quantitative relationships, matching magnitudes and quantities or solving easy word problems. However, the question of whether it is Arabic number or number words processing that is important for maths learning and the relationship with maths fluency and untimed maths learning remains unresolved. Since other existing research is made up of cross-sectional studies (Ashcraft & Moore, 2013; Berteletti, Lucangeli, & Zorzi, 2012; Booth & Siegler, 2006; Ebersbach, Luwel, Frick, Onghena & Verschaffel, 2008; Holloway & Ansari, 2009; Sasanguie et al., 2013; Schneider et al., 2008; Siegler & Booth, 2004; Slusser et al., 2013), it is difficult to make predictions on estimation accuracy and distribution growth.

1.2. Math achievement and language

Although children process numbers long before the acquisition of language (Dehaene, 2001) the value of including language has recently been stressed in the prediction of numeracy development (Praet et al., 2013; Purpura, Hume, Sims & Lonigan, 2011; Romano, Babchishin, Pagani & Kohen, 2010; Sarnecka et al., 2007; Wiese, 2003).

Having a larger nominal vocabulary was found to be helpful in the acquisition of number words (Negen & Sarnecka, 2012). Furthermore, some studies (Barner, Chow & Yang, 2009; Negen & Sarnecka, 2012) revealed that general measures of language development also predicted number-word knowledge, although other studies (e.g. Ansari, Donlan, Thomas, Ewing, Peen & Karmiloff-Smith, 2003) did not find such a link. It remains a point of discussion whether or not language helps children in kindergarten to solve mathematical problems.

1.3. The current study

To summarise, empirical evidence is lacking for age-related changes in estimations in three formats, adding language as a predictor and focusing on timed and untimed mathematic achievement. Moreover, very few studies examined these skills in a longitudinal design from kindergarten till grade 2.

This study addresses the following two major research questions: (a) is the accuracy and distribution of the estimation of the position of numbers using different formats (stimuli as Arabic numerals, spoken number words, and dot patterns) mirroring the familiarity with numbers and predicting untimed and timed maths learning? And, (b) does language explain variation in the growth curves?

Four additional questions or hypotheses were formulated for the first research question. We expected a better accuracy in the estimation of the position of numbers in older children, mirroring their familiarity with numbers (hypothesis 1). Considering the format-independency hypothesis, we expected similar results on the estimation with Arabic numerals, spoken number words, and dot patterns (hypothesis 2). In line with the developmental shift, we expected kindergartners to estimate in a logarithmic manner, and children in grade 1 and grade 2 to follow a more linear curve (hypothesis 3). Finally, we expected different predictions for processing untimed calculation and timed fact retrieval tasks (hypothesis 4).

For the second research question, changes over time were expected with language thus explaining some of the variation in the growth curves (hypothesis 5).

2. Methods

2.1. Participants and procedure

The children in this study (N=132, 53% girls) were Dutch-speaking children from five kindergartens that serve children from families with working and middle-class socio-economic backgrounds. Written parental consent was obtained for all children to participate in the study.

All children were individually tested at kindergarten in a quiet room of the school at measurement time 1 (March kindergarten = time period T1; aged of 68 months, SD=4 months) to obtain measures of intelligence, number estimation and early calculation skills.

Measurements 2 and 3 took place in grade 1 (November grade 1 = time period T2 getting instruction on numbers 0-10, June grade 1 = time period T 3 getting instruction on numbers 0-20). All children were individually tested on their number estimation and ability to solve simple calculations (T2 and T3) as well as on their ability to retrieve number facts (T3).

All children were tested again in grade 2 (October grade 2 = time period T4 rehearsal for instruction on numbers 0-20) on number estimation (T4). Due to constraints in access to schools and the attending children, it was not feasible to collect data on all children at time period 5. Data were collected on half the children in grade 2 (January grade 2 = time period T5 getting instruction on numbers 0-100) on number estimation (T5) and on their ability to calculate (T5).

2.2. Measures

2.2.1. Intelligence

Intelligence was assessed in kindergarten (at T1) with the Wechsler Kindergarten and Primary Scale of Intelligence, the WPPSI-III-NL (Wechsler et al., 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).

2.2.2. 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, the CELF-$_4$Nl (Semel, Wiig & Secord 2008; Kort, Schittekatte & Compaan, 2008). This resulted in a core language score. This test was validated on 1280 children. The internal consistency was good, with Cronbach's alpha between .87 and .95 (D'Hondt et al., 2008).

2.2.3. Number estimation skills

All children were tested with a forced choice number line estimation task in kindergarten (T1 at the age of M=68 months, SD=4 months), November grade 1 (T2) and June grade 1 (T3). Half were followed up in grade 2 (October grade 2 T4, January grade 2 T5).

The Number Line Estimation (NLE) task used a 0-100 scale, in line with Berteletti and colleagues (2010) and Booth and Siegler (2006). The task included three exercise trials and 30 test trials. Stimuli (2, 3, 4, 6, 18, 25, 42, 67, 71 and 86) were presented in three different formats, as Arabic numerals not read aloud to the children (e.g. anchors 0 and 100, target number 25), spoken number words written on the scale (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). A higher proportion of smaller numbers (2, 3, 4, 6, 18) compared to larger numbers (25, 42, 67, 71 and 86) was used to obtain a fine-grained data pattern for the lower number range with children in grade 1, who only know numbers up to 20. Magnitude estimations were compared for three formats. The Arabic numeral and number word estimation tasks were symbolic estimation tasks, with subjects having to make a numerical translation from the assignment of Arabic numerals or number words to their position on a line. The dot estimation task was a magnitude estimation task, with subjects having to estimate a quantity by indicating its position on a line with dots as anchors. The dot patterns were controlled for perceptual variables using the procedure by Dehaene, Izard and Piazza (2005), meaning that in half the trials, dot size was held constant, and in the other half, the size of the total occupied area of the dots was held constant. Children were asked to put a single mark on the line to indicate the location of the number (Berteletti et al., 2010): "We will now play a game with numbers. Look at this page, you can see a long line ranging from zero to ten. Above the line, you can see a number/the number x/ dots. I want you to show me where this number/the number x/the dots should be on the line. If here is zero, and here is ten, where should this number/the number x/these dots be located on the line? If you know where this number/ the number x/ these dots belong, you can make a single mark with your pencil on the line." No feedback was given to participants regarding the accuracy of their marks. The instructions could be rephrased if needed, but no suggestions were given on the correct place of the mark. The Percentage Absolute Error (PAE) – the amount by which their estimated deviated from the correct values – was calculated per child as a measure of children's estimation accuracy following a formula by Siegler and Booth (2004).

PAE = (Estimate – Estimated Quantity Scale of Estimated)/100

For example, if a child was asked to estimate 50 on a 0-100 number line and placed the mark at the point on the line corresponding to 60, the PAE would be 10%, that is (60 - 50) / 100.

2.2.4. Mathematics achievement

To assess maths learning, outcome measures were used focused on what the children are supposed to have learned during formal maths education according to their grade curriculum.

Subtest five of the Tedi-Math (Grégoire, Noël, & Van Nieuwenhoven, 2004) was used to assess kindergarteners' skills (at T1). This untimed subtest consists of simple arithmetic operations to measure early numeracy in kindergarten. The child was presented with simple arithmetic operations in pictures (e.g. 'here you see two red balloons and three blue balloons. How many balloons are there together?'). Cronbach's alpha was .84. The Tedi-Math was used and tested for conceptual accuracy and clinical relevance in previous studies (e.g. Stock, Desoete & Roeyers, 2010).

The TEDI-MATH has proven to be a well validated (Desoete, 2006; 2007a & b) and reliable instrument, values for Cronbach's Alpha 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 till grade 1(Desoete & Grégoire, 2007) and on 240 children assessed in grade 1, 2 or 3 with TEDI-MATH and reassessed two years later with arithmetic tasks (Desoete, 2007). In addition the Flemish data were confirmed with similar data from the French speaking part of Belgium and France (Desoete, Roeyers, Schittekatte, & Grégoire, 2006).

At T2 and T5 children completed the Kortrijk Arithmetic Test Revision (KRT-R; Baudonck et al., 2006) as an untimed general curriculum-based mathematics achievement test. The KRT-R is a standardised test which requires children to 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 …). The test focuses on what children are supposed to have learned about number knowledge, mental arithmetic and procedural calculation according to their grade curriculum. The test is different for grade 1 (T2) and grade 2 (T5). Thus the same constructs are included in each grade but at a different difficulty level. The psychometric value of the test has been demonstrated on a sample of 3,246 children. The validity coefficient (correlation with school results) varies between .64 and .66 and the reliability coefficient (Cronbach's alpha) between .83 and .94, indicating good psychometric values.

At T3 children completed the CDR Test (Desoete & Roeyers, 2006), an untimed curriculum-based standardised test on simple calculations in a number-problem format (e.g. 16 - 12 = …), or in a word-problem format (e.g. 1 less than 8 is …). The psychometric value of the test has been demonstrated on a sample of 1,792 children. The reliability coefficient (Cronbach's alpha) was .93.

At T3 and T5 children also completed the Arithmetic Number Fact Test (Tempo Test Rekenen (TTR; De Vos, 1992), a timed arithmetic test to assess their fact retrieval skills. The TTR (De Vos, 1992) is a test consisting of 80 (first grade) or 200 (second grade) arithmetic number fact problems. In first grade, children have to solve as many additions and subtractions as they can in two minutes, children in the second half of second grade are presented additions, subtractions, divisions and multiplications and have five minutes to solve as many items as possible. The TTR is a standardised test frequently used in Flemish education as measure of early arithmetic acquisition. The total number of correct items was used as score for the analyses. The psychometric value of the TTR has been demonstrated on a sample of 10,059 children in total. The test is identical for periods T3 and T5. The total number of correct items was used for the analyses.

2.3. Analysis procedure

Before testing the hypotheses, the PAEs were log transformed for distributional reasons.

The mean PAE was analysed in kindergarten (T1), grade 1 (T2 and T3) and grade 2 (T4 and T5). In addition, to study the shift from logarithmic to linear representation and the relationship with arithmetic, a number of regression analyses were conducted (in kindergarten, grade 1 and 2). Moreover, the prediction for dots was compared with the predictive value of symbolic stimuli (Arabic digits and number words) simultaneously entered as predictors in the five time periods. Furthermore, regression analyses were conducted to study cross-sectional relationships between the PAE and arithmetic measures in kindergarten (T1), grade 1 (T2 and T3) and grade 2 (T5). Finally, it was explored whether the R^2_{lin} values of linear fits could predict the arithmetic achievement at T1, T2, T3 and T5.

A latent growth curve model was fitted with the intercept as log PAE (accuracy level) and the slope as linear growth rate. The growth model was used to study the changes in relationships between the variables over time. Unnested models were compared based on Akaike Information Criterion (AIC). This AIC is a measure of the relative quality of a statistical model for a given set of data. AIC deals with the trade-off between the complexity of the model and the goodness of fit of the model. The lower the AIC, the better the relative quality of the statistical model. In addition, the following goodness of fit indices were reported: relative chi-square (χ^2/df) attempting to make the index less dependent on the model complexity, the Comparative Fit Index (CFI) and the Root Mean Square Error or Approximation (RMSEA) that doesn't require comparison with a null model.

3. Results

3.1. Descriptive statistics

IQ and language were assessed in kindergarten. Children had an average Total Intelligence (TIQ; M = 101.39, SD =12.73). Verbal Intelligence (VIQ; M = 102.74; SD =11.97) and Performance Intelligence (PIQ; M = 99.29, SD =11.68) were assessed as averages with the WPPSI. The language core index on the CELF-IV was 98.17 (SD = 11.40).

3.2. Numerical estimation and development

3.2.1. Estimation accuracy : development from kindergarten till the middle of grade 2

The magnitude representation inaccuracy in the total test, or the PAE in the estimation for all 30 trials (format independent) on the number line task, and the results for the different formats from kindergarten to grade 2 is described in Table 1.

Table 1: Percentage of Absolute Error (PAE) for the different modalities

	Period1 *M (SD)*	Period2 *M (SD)*	Period3 *M (SD)*	Period4 *M (SD)*	Period5 *M (SD)*
Dots	*24.84 (8.41)*	*18.78 (8.44)*	*17.02 (8.07)*	*13.60 (5.04)*	*13.49 (4.76)*
Arabic numbers	*25.10 (10.66)*	*17.55 (7.98)*	*13.25 (6.86)*	*10.73 (5.41)*	*9.58 (5.52)*
Number words	*25.03 (10.78)*	*17.61 (7.79)*	*13.70 (6.19)*	*11.24 (5.25)*	*9.70 (5.05)*
Total PAE	*24.84 (8.41)*	*17.98 (7.72)*	*14.60 (6.20)*	*11.86 (4.47)*	*10.95 (4.50)*

Table 1 reveals that the overall estimations become more accurate when children get older and more familiar with numbers. The PAE decreased 6.51% from kindergarten to the beginning of grade 1. The PAE only decreased 2.26% from the end of grade 1 to October of grade 2, thus the decrease slows down . However, children made less errors (PAE decreased) from kindergarten to grade 2.

3.2.2. Estimation accuracy: format-indepency

Pairwise comparisons between the PAEs for Arabic numerals revealed significant differences between time periods 1 and 2 ($p < .001$) , periods 2 and 3 ($p < .001$), periods 3 and 4 ($p \leq .001$) but not between periods 4 and 5 ($p = .239$).

The pairwise comparisons between the PAEs on number words revealed no significant differences between time periods 1 and 2 ($p < .603$) , or between periods 2 and 3 ($p = .215$), and a significant difference between periods 3 and 4 ($p \leq .001$), and periods 4 and 5 ($p = .024$).

Pairwise comparisons of the PAEs on dots revealed no significant differences between time periods 1 and 2 ($p = .548$) , periods 2 and 3 ($p = .272$), and a significant difference between periods 3 and 4 ($p \leq .001$), but not between periods 4 and 5 ($p = .682$).

Thus if format-independent the estimations become more accurate from kindergarten (period 1) to the end of grade 1 (period 3) on all estimation tasks (using Arabic numerals, number words or dots as formats). Additionally, format-independently there was no significant difference between the estimation accuracy at the beginning (period 4) and middle (period 5) of grade 2.

3.2.3. Estimation : developmental shift in the distribution

The first regression analyses conducted on a group level for all 30 trials (in kindergarten, grade 1 and 2) revealed a significant logarithmic representation ($p < .001$) in kindergarten for the total number line test (see le Table 1 and Figure 1). The representation with Arabic numbers ($p < .001$), number words ($p < .001$) and dots ($p < .001$) also had a logarithmic distribution.

In November of grade 1children had significant logarithmic representations of numbers in the total test ($p < .001$), see Table 2 and Figure 2. The representation with Arabic numbers ($p < .001$), number words ($p < .001$) and dots ($p < .001$) also had a logarithmic distribution.

At the end of grade 1 children had a significant logarithmic representation on the total test ($p < .001$), see Figure 3 and Table 2. The representation with Arabic numbers ($p < .001$), number words ($p < .001$) and dots ($p = .003$) also had a logarithmic distribution.

At the beginning of grade 2 children had significant linear representations in the total test ($p = .033$), see Figure 4 and Table 2. The representation with number words ($p = .002$) had a linear distribution. This was not the case for Arabic numbers ($p = .528$) and dots ($p = .119$).

In the middle of grade 2 ($p = .323$), there were significant linear distributions for Arabic numbers ($p = .009$), number words ($p = .004$) and dots ($p = .047$), see Figure 5 and Table 2

Table 2: Distributions of estimations from kindergarten till grade 2. * p<.05

	R^2log	*p*log	R^2lin	*P*lin	*T*	*p*
Kindergarten Time 1						
Total test	.959	<.001	.729	.002	*t*(129)= 12.712	<.001*
Arabic	.946	<.001	.751	.001	*t*(129)= 8.561	<.001*
N. words	.968	<.001	.766	.001	*t*(129)=5.935	<.001*
Dots	.927	<.001	.740	.001	*t*(129)= 8.304	<.001*
Grade1 Time 2						
Total test	.970	<.001	.843	<.001	*t*(129)=8.096	<.001*
Arabic	.976	<.001	.848	<.001	*t*(129)=8.777	<.001*
N.words	.984	<.001	.894	.001	*t*(129)=6.497	<.001*
Dots	.751	.001	.737	<.001	*t*(129)=4.112	<.001*
Grade1 Time 3						
Total test	.970	<.001	.843	<.001	*t*(126)= 5.962	<.001*
Arabic	.976	<.001	.848	<.001	*t*(126)=5.456	<.001*
N. words	.984	<.001	.894	<.001	*t*(126)=5.595	<.001*
Dots	.751	<.001	.737	<.001	*t*(126)=3.070	.003*
Grade2 Time 4						
Total test	.933	<.001	.955	<.001	*t*(120)=-2.155	.033*
Arabic	.933	<.001	.967	<.001	*t*(120)=-0.633	.528
N. words	.954	<.001	.958	<.001	*t*(120)=-3.221	.002*
Dots	.856	<.001	.899	<.001	*t*(120)=-1.569	.119
Grade2 Time5						
Total test	.892	<.001	.977	.<001	*t*(61)=-0.997	.323
Arabic	.888	<.001	.992	<.001	*t*(61)=-2.701	.009*
N. words	.890	<.001	.992	<.001	*t*(61)=-2.953	.004*
Dots	.863	<.001	.932	<.001	*t*(61)=-2.029	.047*

Because of the longitudinal design it was also possible to look on a more individual level at the evolution of the number of children having linear representations over time (see Table 3).

Table 3: Percentage of children having a linear and logarithmic representation

	Lin representation	Log representation	No representation
Kindergarten			
Arabic	6.8%	49.2%	42.4%
Number words	11.4%	45.5%	41.7%
Dots	9.8%	50%	38.6%
Start of grade 1			
Arabic	20.2%	74.4%	5.4%
Number words	29%	65%	6%
Dots	27.9%	44.2%	27.9%
End of grade 1			
Arabic	32.2%	63.8%	3.9%
Number words	32.3%	61.4%	6.3%
Dots	35.4%	55.2%	9.4%
Start of grade 2			
Arabic	52.5%	45.8%	1.7%
Number words	41.7%	56.6%	1.7%
Dots	46,7%	46.5%	6.8%
Middle grade 2			
Arabic	62.3%	32.8%	5%
Number words	60.7%	36.0%	3.3%
Dots	59.0%	32.8%	8.2%

Analyses revealed that most children in kindergarten had logarithmic or no valid representations on the number-to-position task of the 0-100 number line using symbolic stimuli (Arabic numbers, number words) or non-symbolic (dots) stimuli. At the start of grade 1, when children received instruction on numbers 0-10, almost all children had valid but logarithmic representations for Arabic numbers and number words. At the end of grade 1, with children becoming familiar with numbers up to 20, about one third had linear representations, whereas two thirds still had more logarithmic representations of numbers 0-100 on all formats. At the start of grade 2 more than half of the children had linear representations of Arabic numbers whereas this was only the case for 41.7% and 46.7% of the representation with number words or dots as stimuli. In the middle of grade 2 the representation became linear for nearly 60% of the children on all formats.

3.2.4. Estimation : relationship with maths learning

First, the relationship between estimation accuracy and maths learning was analysed (see Table 4). The cross-sectional relationship between early mathematics in kindergarten was significant (F (3, 128) = 11.966, $p < .001$, R^2 = .223) for the PAE of Arabic digits (p = .013), but not for the PAE of number words (p = .384) nor for the PAE of dots (p = .900).

Table 4: Predictions with math learning as outcome in kindergarten, grade 1 and grade 2

	Unstandardized Coefficients	β	t	*p*
Kindergarten (T1)	**Early math**			
Constant	14.330		11.209	.000
PAE Dots	-.008	-.014	-0.126	.900
PAE Arabic Numbers	-.211	-.363	-2.517	.013
PAE Number words	-.056	-.117	-0.874	.384
Grade 1 (T2)	**Untimed calculations**			
Constant	50.030		21.149	.000
PAE Dots	-.281	-.221	-1.646	.102
PAEArabic Numbers	-.234	-.167	-1.01	.315
PAE Number words	.057	.045	0.276	.783
Grade 1 (T3)	**Timed fact retrieval**			
Constant	25.947		17.899	.000
PAE Dots	-.052	-.066	-0.534	.595
PAEArabic Numbers	-.131	-.142	-0.966	.336
PAE Number words	-.061	-.058	-0.382	.703
Grade 1 (T3)	**Untimed calculations**			
Constant	31.761		24.419	.000
PAE Dots	.003	.004	0.032	.975
PAE Arabic Numbers	-.063	-.069	-0.517	.606
PAE Number words	-.414	-.406	-2.906	.004
Grade 2 (T5)	**Untimed calculations**			
Constant	35.536		9.817	.000
PAE Dots	-.153	-.072	-.543	.590
PAE Arabic Numbers	-.414	-.226	-1.315	.194
PAE Number words	-.616	-.307	-2.016	.048
Grade 2 (T5)	**Timed fact retrieval**			
Constant	59.332		10.248	.000
PAE Dots	.207	.072	.462	.646
PAEArabic Numbers	.075	.030	.152	.880
PAE Number words	-1.100	-.399	-2.255	.028

**p* ≤ .05 Note. PAE = Percentage Absolute Error

The regression analysis at the start of grade 1 on untimed calculation skills (*F* (3, 121) = 4.676, *p* = .004, R^2 = .326) revealed a trend for the PAE with dots (*p* =.102) but not for Arabic numerals (*p* = .315) or number words (*p* =.783; see Table 4). The regression analysis was not significant for timed fact retrieval (*F* (3, 123) = 2.473, *p* = .065, R^2 = .058).

The regression analysis (on half the children) in the middle of grade 2 was significant for untimed calculation (*F* (3, 62) = 7.560, *p* = .000, R^2 = .278), especially for the PAE of number words (*p* =. 048). The prediction for timed fact retrieval was not significant (*F* (3, 54) = 2.586, *p* < .063, R^2 = .132).

Further, we explored whether the linearity of the distribution (R^2_{lin} values of linear fits) could predict maths learning. This was marginally the case in kindergarten (*F* (1, 129) = 3.766, *p* = .055, R^2 = .029) but not at the beginning of grade 1 (*F* (1, 125) = 2.347, *p* = .128, R^2 = .019). At the end of grade 1 the regression analysis was significant for untimed maths learning (*F* (1, 124) =20.758, *p* < .001, R^2 = .144, but not for timed fact retrieval (*F* (1, 124) = 3.551, *p* = .062, R^2 = .028). Moreover, untimed maths learning could be predicted by the number line linearity in the middle of grade 2 (*F* (1, 59) = 18.832, *p* < .001, R^2 = .245), but this was not the case for timed fact retrieval (*F* (1, 54) = 1.821, *p* = .183, R^2 = .033).

3.3. Language and maths learning: Growth model

To investigate hypothesis 5, a latent growth curve model was firstly fitted with log PAE (accuracy level) as an outcome variable and random intercept and random slope as a linear growth rate. The fit of this model was acceptable based on TLI and CFI (NNFI (TLI) =.878) and CFI = .943 but not acceptable based on $\chi 2$/df= 2.517 and RMSEA = .108. The estimated intercept for log PAE (mean log PAE at T1) was 3.175 (95% CI: 3.11 to 3.24). The estimated overall change in log PAE (change in log PAE between T 1 and 5) was -0.8 (95%CI: -0.88 to -0.72). In terms of the PAE, this meant that the estimated geometric mean for the PAE in kindergarten was 23.9 (95% CI: 22.4 to 25.6). The PAE decreased with 54.9% (95% CI: 51.3% to 58.3%) between the end of kindergarten and the middle of grade 2. There was significant interindividual variation for the intercept (estimated *SD*=0.308; *p* < .001) but not for the slope (estimated *SD* = 0.18; Walt test *p* = .266; generalised variance Likelihood Ratio Test *p* = .42), meaning that there was significant variability between the children on estimation accuracy (intercepts) but not in evolution of their growth curves.

When the different modalities were analysed, the Wald test (p =.027) and generalised variance test (Likelihood Ratio Test; p = .033) revealed significant variability between the children for the intercepts and slopes using dots as stimuli. However, there was only significant variability for the intercepts but not for the slopes using Arabic numbers (Wald test p = .497; Likelihood Ratio Test p = .25) and number words (Wald test p = .26; Likelihood Ratio Test p = .36).

In a next step, chi-squared was used to compare the model with and without the interaction between slope and IQ (24.217 vs. 20.360, df=1; p = .049), leading to the choice of a model with IQ x slope interaction and IQ x intercept interaction. Intelligence had a significant effect (p = .05) on interindividual differences on slope, so the interaction was included in the model. The fit of this model was acceptable (NNFI (TLI) =.904) with $\chi 2$/df= 2.036, RMSEA = .089 and CFI= .954.

Intelligence explained a significant part (p <.001) of interindividual variability in intercepts of the log PAE. There was also a trend for IQ explaining (p = .05) interindividual variability in the slopes of the log PAE. Standard deviation of the intercepts was reduced from 0.31 to 0.245 by adding IQ as a predictor. Standard deviation of the slopes was only slightly reduced from 0.179 to 0.182 by adding IQ as a predictor. With 1 point increase in IQ the PAE in kindergarten decreased with 1.5% (95% CI: -1.1% to -1.9%). For an increase of 10 points in IQ the PAE for T1 is expected to decrease with 13.9% (95% CI: -17.3% to -10.4%). In addition, for one point increase in IQ the slope of the PAE (PAE at T5- PAE at T1) is expected to increase with 0.5% (95% CI: -1.1% to -1.9%). For an increase of 10 IQ points the slope of PAE (PAE at T5 - PAE at T1) is expected to decrease with 5.5% (95% CI: 0% to 1.11%).

To investigate whether language could explain some of the interindividual variation in the "growth curves" (hypothesis 5) chi-squared was used to compare the model with and without the interaction between language and slope (20.146 vs. 19.303 df=1; p=.36) leading to the choice of a model without language*slope interaction. The fit of this model (see Figure 10) was good (NNFI (TLI) =.915) with $\chi 2$/df= 1.831, RMSEA = .08, CFI= .956 and AIC = 52.146.

Language had a significant effect on the intercept (estimate -.011, S.E. .002, C.R. -4.977, p = .002) but not on growth, meaning that for a one unit increase in the language core index the PAE in kindergarten is expected to decrease with 1.1% (95% CI: 0.7% to 1.5%).

4. Discussion

The importance of predictors for the development of mathematics has been demonstrated (e.g. Kolkman, Kroesbergen, & Leseman, 2013). The current study is the first to simultaneously tap the contribution of number words in addition to estimation using Arabic numbers and dots in the acquisition of timed and untimed mathematic skills. Additionally, the importance of language for successful number line estimation was studied. Thus, the progression in accuracy, format specificity and the relationship with timed and untimed mathematic achievement was investigated with a number line task on a 0-100 scale.

The first aim was to examine number line estimation and development.

Firstly, the results of the analyses were in concordance with hypothesis 1 and in line with previous cross-sectional research (e.g. Ashcraft & Moore, 2012; Geary et al., 2008; Moeller et al., 2009; Muldoon et al., 2013; Sasanguie et al., 2013) revealing that number line estimation errors on the 0-100 scale declined with age and instruction. There was a steady decrease in absolute errors from kindergarten to grade 1 and a moderate decrease in errors in grade 2.

Secondly, there was mixed evidence for the format-independency of estimation (hypothesis 2). In line with the format-independency and studies of Barth and colleagues (2003), estimations became more accurate on all estimation tasks (using Arabic numerals, number words or dots as formats). However, in constrast with the format-independency, our findings suggested that, at an early age, more children had linear distribution for number words. The number words, in particular, became format important in grade 2.

Thirdly, the shift from a logarithmic to a linear representation of numbers (hypothesis 3) was confirmed. Kindergartners, the children in grade 1 had significant logarithmic representations of numbers on a 0-100 scale. In addition, there was a linear distribution in grade 2. These results are in line with the majority of Siegler and Booth's (2004) findings. Fourthly, the relationship between estimation and untimed and timed maths learning was studied (hypothesis 4). Untimed maths learning, in particular, could be predicted. These findings are in line with Sasanguie et al. (2013) that estimation on a number line is especially correlated with calculation skills and less with timed arithmetic or fact retrieval skills. Moreover, our findings revealed that number words became important in prediction in grade 2. This might perhaps be explained by the inversion principle of two-digit number word names in Dutch (e.g. “een-en-zeventig”, literally “one-and-seventy”, for 71). Seron and Fayol (1994) showed that due to irregularities in the number word system, second graders from France made more errors on items comprising these numbers in different tasks (e.g. transcoding numbers from verbal to Arabic notation, transcoding numbers from verbal notation to representation with tokens, grammaticality judgements) compared to second graders from Wallonia. Dowker, Bala and Lloyd (2008) showed that Welsh speaking children (with a regular number word system) were better at magnitude comparison of two-digit numbers, but not in arithmetic, compared to English speaking peers (with an irregular number word system) (Dowker, Bala, & Lloyd, 2008).

The second aim of this study was to investigate whether language could explain some of the interindividual variations in the growth curves (hypothesis 5). Our analysis revealed that intelligence (assessed in kindergarten) explained part of the variability in intercepts and slopes, whereas language (also assessed in kindergarten) explained variation when children enter the school system (in kindergarten) but not in the evolution of growth curves. These findings are in line with Ansari and colleagues (2003), meaning that language influenced the starting point but not the development or evolution of the estimation accuracy.

Even longitudinal studies have their limitations. Firstly, one of the limitations is that we relied on the estimation of a limited set of numbers in different formats. Several studies (Berteletti et al, 2010; Booth & Siegler, 2006) have used twice the amount of trials. In this study the function fits were calculated on 30 data points. Our decision to use three exercise trials and 30 test trials with 2, 3, 4, 6, 18, 25, 42, 67, 71 and 86 as stimuli was theoretically motivated since we were especially interested in the three formats. Nevertheless, we have to mention the study by Gunderson, Ramirez, Beilock and Levine (2012) and Ebersbach et al. (2008), where lesser numbers were used without resulting in instable responses from the children. Secondly, only half the children were followed up in grade 2. This choice of following up only half the children in the middle of grade 2 was motivated by constraints in accessing schools and the attending children. The children did not drop out, so the missing data was random. Finally, we have to acknowledge that not all authors consider the number line task as a task that measures numerical representations. Some (e.g., Barth & Paladino, 2011) see it as a measure of proportional judgment. In addition, evidence for a segmented linear model has been revealed by Ebersbach and colleagues (2008), and a M-shaped pattern was described by Ashcraft and Moore (2012) beginning in third graders' errors and fourth graders' latencies, suggesting that estimation comes to rely on a midpoint strategy, based on children's growing number knowledge (i.e., knowledge that 50 is half of 100). We did not run analyses in terms of shape of the distribution of estimations (bi-linear, M-shaped etc.) because of the limited estimation points in our task and because this was beyond the scope of this study.

Nevertheless, the current study has educational merits in providing longitudinal evidence for the importance of familiarity with numbers leading to better estimation and untimed maths proficiency. Perhaps, in line with Obersteiner, Reiss and Ufer (2013), a preventive support or increased 'additional focusing on the position of numbers' for low performing kindergartners can enhance their maths skills. This needs to be addressed in future studies. The results also suggest that children enter kindergarten with different language skills, but language does not explain the growth of estimation skills. Such knowledge is necessary in order to inform researchers and professionals about the value of testing language in kindergarten.

References

Ansari, D., Donlan, C., Thomas, M. S. C., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology, 85*, 50-62. http://dx.doi.org/10.1016/S0022-0965(03)00026-2.

Ashcraft, M. H., & Moore, A. M. (2012). Cognitive processes of numerical estimation in children. *Journal of Experimental Child Psychology, 111*, 246–267. http://dx.doi.org/ 10.1016/j.jecp.2011.08.005.

Barner, D., Chow. K., & Yang, S. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58, 195-219*. http://dx.doi.org/10.1016/j.cogpsych.2008.07.001.

Barth, H., Kanwisher, N., & Spelke, E. (2003). The construction of large number representation in adults. *Cognition, 86,* 201-221. http://dx. doi.org/10.1037/a0013046.

Barth, H**.,** & Paladino, A.M. (2011). The development of numerical estimation: Evidence against a representational shift. *Developmental Science 14, 125-135.* http://dx. doi.org/10.1111/j.1467-7687.2010.00962.x.

Baudonck, M., Debusschere, A., Dewulf, B., Samyn, F., Vercaemst, V., & Desoete, A. (2006). Kortrijkse Rekentest Revisie (KRT-R) [Kortrijk Arithmetic Test Revision]. Kortrijk: Revalidatiecentrum Overleie.

Bertelli, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers. *Developmental Psychology, 46*, 545-551. http://dx.doi.org/10.1037/a0017887.

Berteletti, I., Lucangeli, D., & Zorzi, M. (2012). Representation of numerical and non-numerical order in children. *Cognition, 124,* 304-313. http://dx.doi.org/101016/j.cognition.2012.05.015.

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology, 42*, 189-201. http://dx.doi.org/10.1037/0012-1649.41.6.189.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44,* 1–42. http://dx.doi.org/ 10.1016/0010-0277(92)90049-n.

Dehaene, S. (1997). *The Number Sense. How the Mind Creates Mathematics*. New York: Oxford University Press.

Dehaene, S. (2001). Précis of "the number sense". *Mind and Language, 16,* 16–32. http://dx.doi.org/ 10.1111/1468-0017.00154.

Dehaene, S., & Cohen, L. (1995). Towards an anatomical and functional model of number processing. *Mathematical Cognition*, *1*, 83-120

Dehaene, S., Izard, V., & Piazza, M. (2005). Control over non-numerical parameters in numerosity experiments. Unpublished manuscript (available at http://www.unicog.org/…/DocumentationDotsGeneration.doc).

De Smedt, B., Noël, M-P., Gilmore, C., & Ansari, D. (2013). How do symbolic and non-symbolic numerical magnitude processing skills relate to individual differences in children's mathematical skills? A review of evidence from brain and behavior. *Trends in Neuroscience and Education*, *2*, 48-55. http://dx.doi.org/10.1016/j.tine.2013.06.001.

Desoete, A., & Roeyers, H. (2006). *Cognitieve Deelvaardigheden Rekenen (CDR).* Herenthals: VVL.

Desoete, A. (2006). Validiteitsonderzoek met de TEDI-MATH. *Diagnostiek-wijzer*, *9*, 140-157.

Desoete, A. (2007a). Students with mathematical disabilities in Belgium: from definition, classification and assessment to STICORDI devices. (pp. 181-222). In T.E. Scruggs & M.A. Mastropieri (Eds.), Advances in Learning and Behavioral Disabilities, Vol. 20. International Perspectives Amsterdam & Oxford: Elsevier Press.

Desoete, A. (2007b). De TEDI-MATH. De plaats van de Tedi-Math in de diagnostiek van dyscalculie in Vlaanderen. Caleidoscoop, 19 (6), 6-19.

Desoete, A., Roeyers, H., Schittekatte, M., & Grégoire, J. (2006). Dyscalculie-gevoelige kennis en vaardigheden in het basisonderwijs in Vlaanderen, Wallonië en Frankrijk. Pedagogische Studieën, 83, 105- 121

De Vos, T. (1992). Tempo Test Rekenen Nijmegen, The Netherlands: Berkhout.

D'Hondt, M., Desoete, A., Schittekatte, M., Kort, W., Compaan, E., Neyt, F., Polfiet, M., & Surdiacourt, S. (2008). De CELF-4-NL: een opvolger voor de TvK? Signaal, 65, 4-16.

Dowker, A., Bala, S., & Lloyd, D. (2008). Linguistic Influences on Mathematical Development: How important is the transparency of the counting system? *Philosophical Psychology*, *21*, 523-538. http://dx.doi.org/10.1080/09515080802285511.

Ebersbach, M., Luwel, K., Frick, A., Onghena, P., & Verschaffel, L. (2008). The relationship between the shape of the mental number line and familiarity with numbers in 5 to 9 year old children: Evidence for a segmented linear model. *Journal of Experimental Child Psychology*, *99*, 1-17. http://dx.doi.org/10.1016/jjecp.2007.08.006.

Geary, D. C., Hoard, M. K., Nugent, L., & Byrd-Craven, J. (2008). Development of number line representations in children with mathematical learning disability.

Developmental Neuropsychology, 33, 277-299. http://dx.doi.org/10.1080/87565640801982361.

Grégoire, J., Noël, M., & Van Nieuwenhoven (2004). *Tedi-Math.* Antwerpen: Harcourt.

Gunderson, E.A., Ramirez, G., Beilock, S.L., & Levine, S.C. (2012). The relation between spatial skill and early number knowledge: the role of the linear number line. *Developmental Psychology, 48*, 1229-1241. http://dx.doi.org/10.1037/a0027433.

Hendriksen , J., & Hurks, P. (2009) *WPPSI-III-NL Wechsler Preschool and Primary Scale of Intelligence*. Pearson Assessment and Information B.V.

Holloway, I.D., & Ansari, D. (2009) Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's math achievement. *Journal of Experimental Child Psychology, 103*, 17-29. http://dx.doi.org/10.1016/j.jecp.2008.04.001.

Huntley-Fenner, G., & Cannon, E. (2000). Preschoolers' magnitude comparisons are mediated by a preverbal analog mechanism. *Psychological Science, 11*, 147-152. http://dx.doi.org/ 10.1111/1467-9280.00230.

Kolkman, M.E., Kroesbergen, E.H., & Leseman, P.P.M. (2013). Early numerical development and the role of non-symbolic and symbolic skills. *Learning and Instruction, 25*, 95-103. http://dx.doi.org/10.1016/j.learninstruc.2012.001.

Kort, W., Schittekatte, M., & Compaan,E.,(2008) *CELF-4-NL Test voor diagnose en evaluatie van taalproblemen. Handleiding [Test for the evaluation of language problems. Manual]*. Amsterdam: Pearson.

Moeller, K., Pixner, S., Kaufmann, L., & Nuerk, H-C. (2009). Children's early mental number line: logarithmic of decomposed linear? *Journal of Experimental Child Psychology, 103*, 503-515. http://dx.doi.org/10.1016/j.jecp.2009.02.006.

Muldoon, K., Towse, J., Simms, V., & Menzies, V. (2013). A longitudinal analysis of estimation, counting skills and mathematical abilities across the first school year. *Developmental Psychology, 49*, 250-257. http://dx.doi.org/ 10.1037/a0028240.

Mundy, E., & Gilmore, C. K. (2009). Children's mapping between symbolic and non-symbolic representations of number. *Journal of Experimental Child Psychology, 103*, 490–502. https://dspace.lboro.ac.uk/2134/8765.

Negen, J., & Sarnecka, B.W. (2012). Number-Concept Acquisition and General Vocabulary Development, *Child Development*, 83, 2019-2027. http://dx.doi.org/10.1111/j.1467-8624.2012.01815.x.

Obersteiner, A., Reiss, K., & Ufer, S. (2013). How training on exact or approximate mental representations of number can enhance first-grade students' basic number processing and arithmetic skills. *Learning and Instruction*, *23*, 125-135, http://dx.doi.org/10.1016/j.learninstruc.2012.08.004.

Praet, M., Titeca, D., Ceulemans, A., & Desoete, A. (2013). Language in the prediction of arithmetic in kindergarten and grade 1. *Learning and Individual Differences,* http://dx.doi.org/10.1016/j.linidif.2013.07.003.

Purpura, D.J., Hume, L.E., Sims, D,C., & Lonigan, C.J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology, 110*, 647-658, http://dx.doi.org/10.1016/j.jecp.2011.07.004.

Romano, E., Babchishin, L. Pagani, L.S., & Kohen, D. (2010). School readiness and later achievement: Replication and extension using a nationwide Canadian survey. *Developmental Psychology, 46*, 995-1007. http://dx.doi.org/10.1037/a0018880.

Sarnecka, B.W., Kamenskaya, V.G., Yamana, Y., Ogura, T., & Ydovina, Y.B. (2007). From grammatical number to exact numbers: early meanings of one, two and three in English, Russian and Japanese, *Cognitive Psychology, 55*, 136-168. http://dx.doi.org/10.1016/j.cogpsych.2006.09.001.

Sasanguie, D., Göbel, S.M., Moll, K., Smets, K., & Reynvoet, B. (2013). Approximate number sense, symbolic number processing, or number-space mappings: What underlies mathematics achievement? *Journal of Experimental Child Psychology, 114*, 418-431. http://dx.doi.org/10.1016/j.jecp.2012.10.012.

Semel, E., Wiig, E. H., & Secord W.A.(2008). *CELF 4 Nl Clinical Evaluation of language Fundamentals*. Amsterdam :Pearson.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75,* 428-444. http://dx.doi.org/10/1111/j.1467-8624.2004.00684.x.

Siegler, R.S., & Opfer, J.E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science, 14,* 237-243. http://dx.doi.org/10.1111/1467-9280.02438.

Schneider, M., Heine, A., Thaler, V., Torbeyns, J., De Smedt, B., Verschaffel, L., . . . Stern, E. (2008). A validation of eye movements as a measure of elementary school children's developing number sense. *Cognitive Development, 23,* 409-422. http://dx.doi.org/10.1016/j.cogdev.2008.07.002.

Seron, X., & Fayol, M. (1994). Number transcoding in children: A functional analysis. *British Journal of Developmental Psychology, 12,* 281-300. http://dx.doi.org/10.1111/j.2044-835X.1994.tb00635.x.

Slusser, E.B., Santiago, R.T., & Barth, H.C. (2013). Developmental change in numerical estimation. *Journal of Experimental Psychology, 142,* 193-208. http://dx.doi.org/10.1037/a0028560.

Stock, P., Desoete, A., & Roeyers, H. (2010). Detecting children with arithmetic disabilities from kindergarten: Evidence from a three year longitudinal study on the role of preparatory arithmetic abilities. *Journal of Learning Disabilities*, *43*, 250-268. http://dx.doi.org/10.1177/0022219409345011.

Van Luit, J.E.H., & Schopman, A.M. (2000). Improving early numeracy of young children with special educational needs. *Remedial and Special Education*, *21*, 27-40. http://dx.doi.org/10.1177/074193250002100105

Wechsler, D., Kort,W., Schittekatte, M., Bosmans, M., Compaan, E.L., Dekker, P.H., &Verhaeghe, P. (2002). Wechsler Intelligence Scale for Children-III-Nl. Amsterdam, The Netherlands: Harcourt.

Wiese, H. (2003). Iconic and non-iconic stages in number development: the role of language. *Trends in Cognitive Science, 7*, 385-390. http://dx.doi.org/10.1016/S1364- 6613(03)00192-X.

116 CHAPTER 4

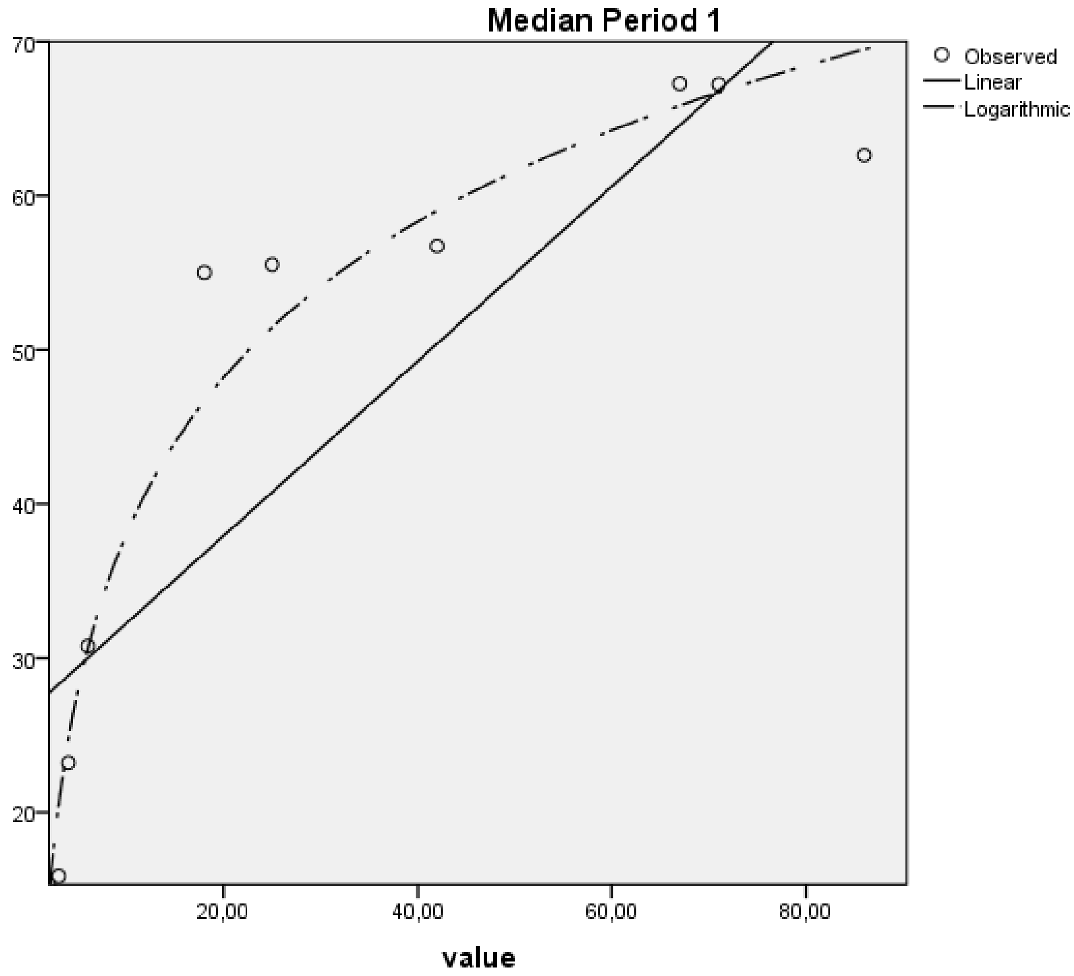


Figure 1: Representation in kindergarten

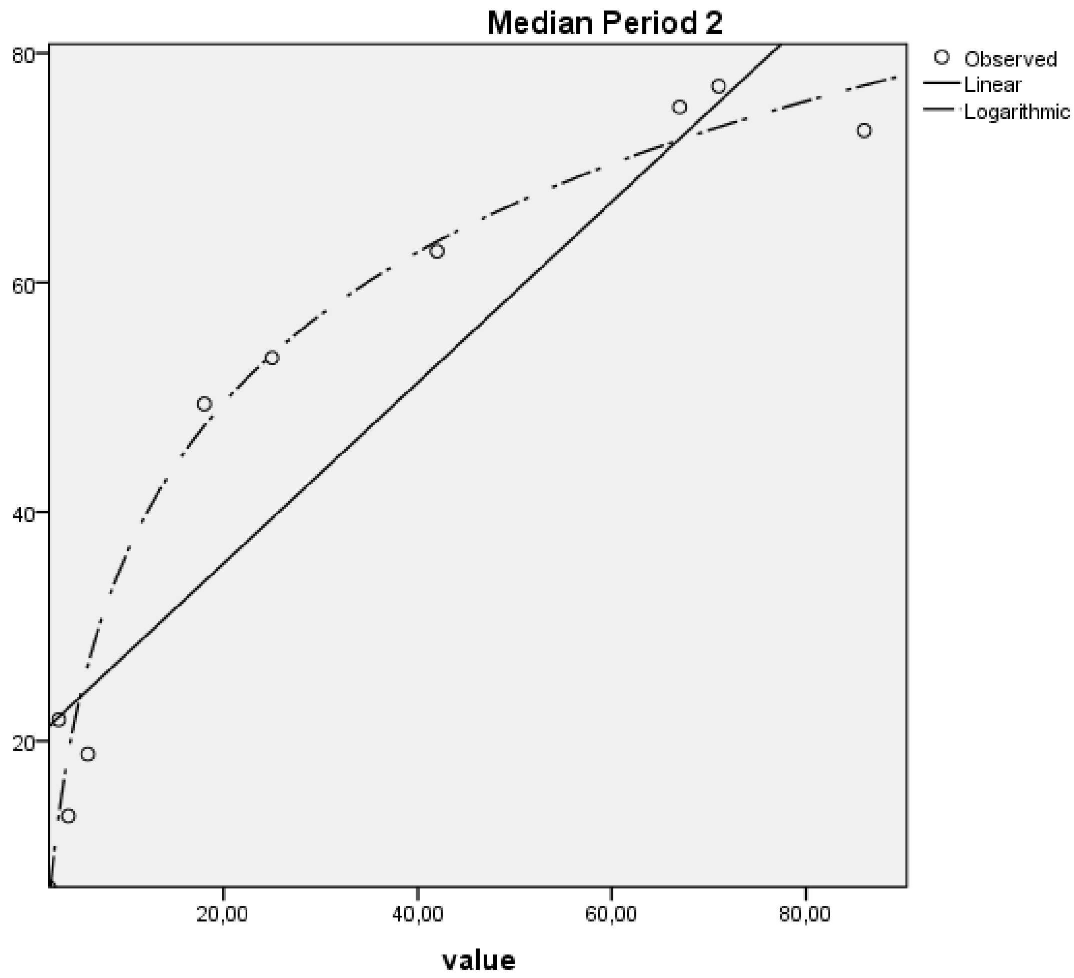


Figure 2: Representation at the beginning of grade 1

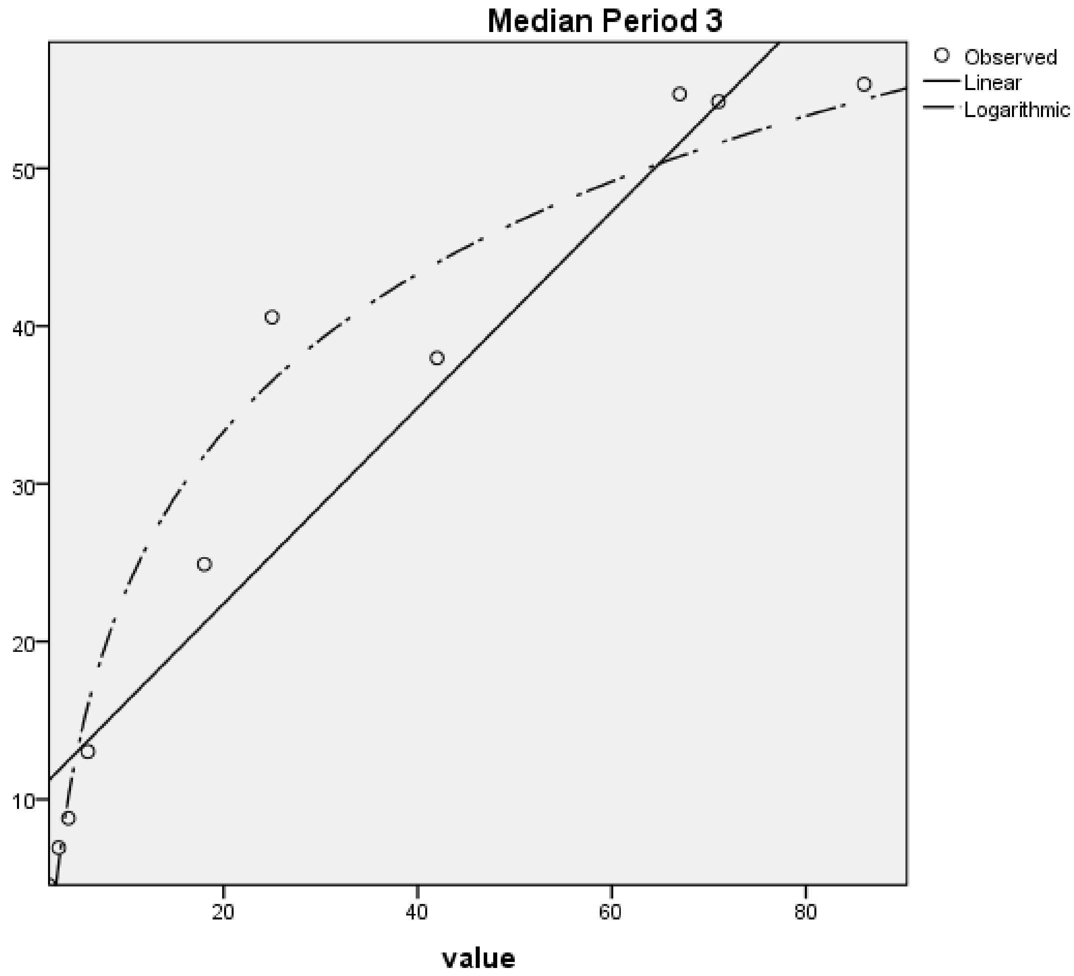


Figure 3: Representation at the end of grade 1

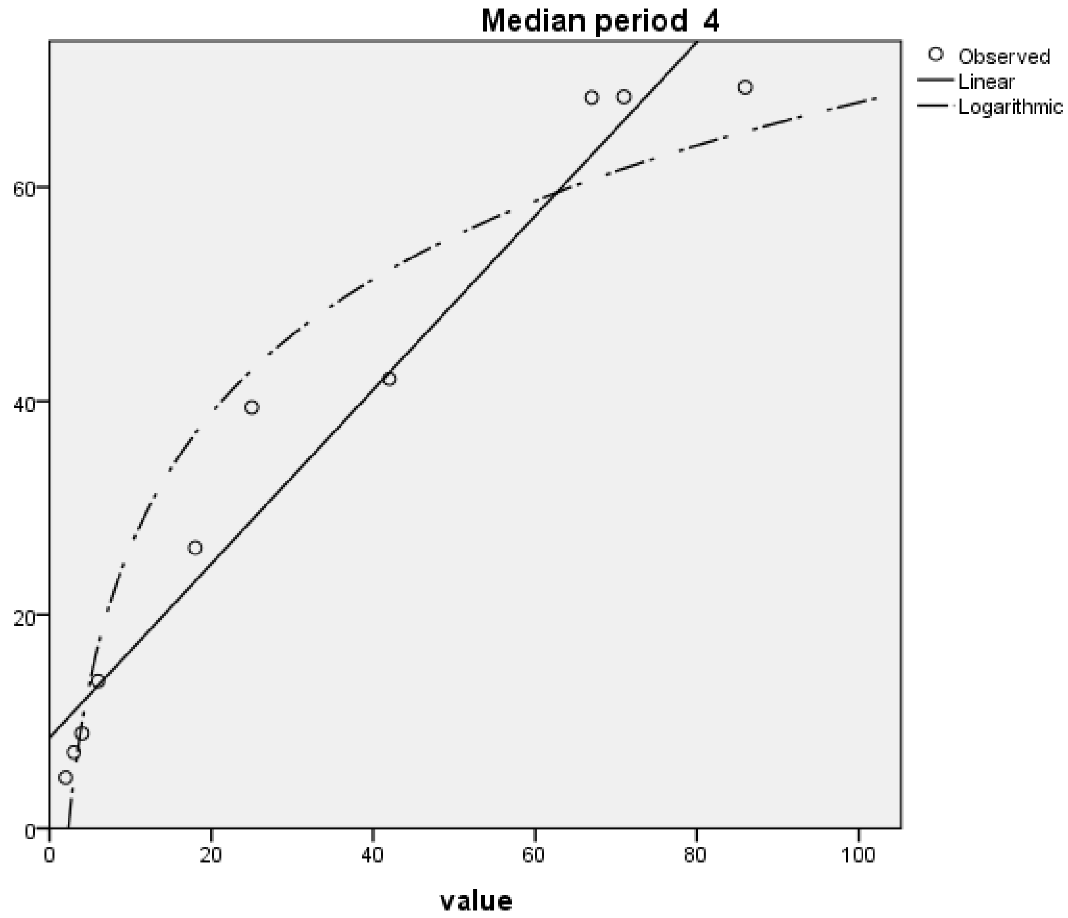


Figure 4: Representation at the beginning of grade 2

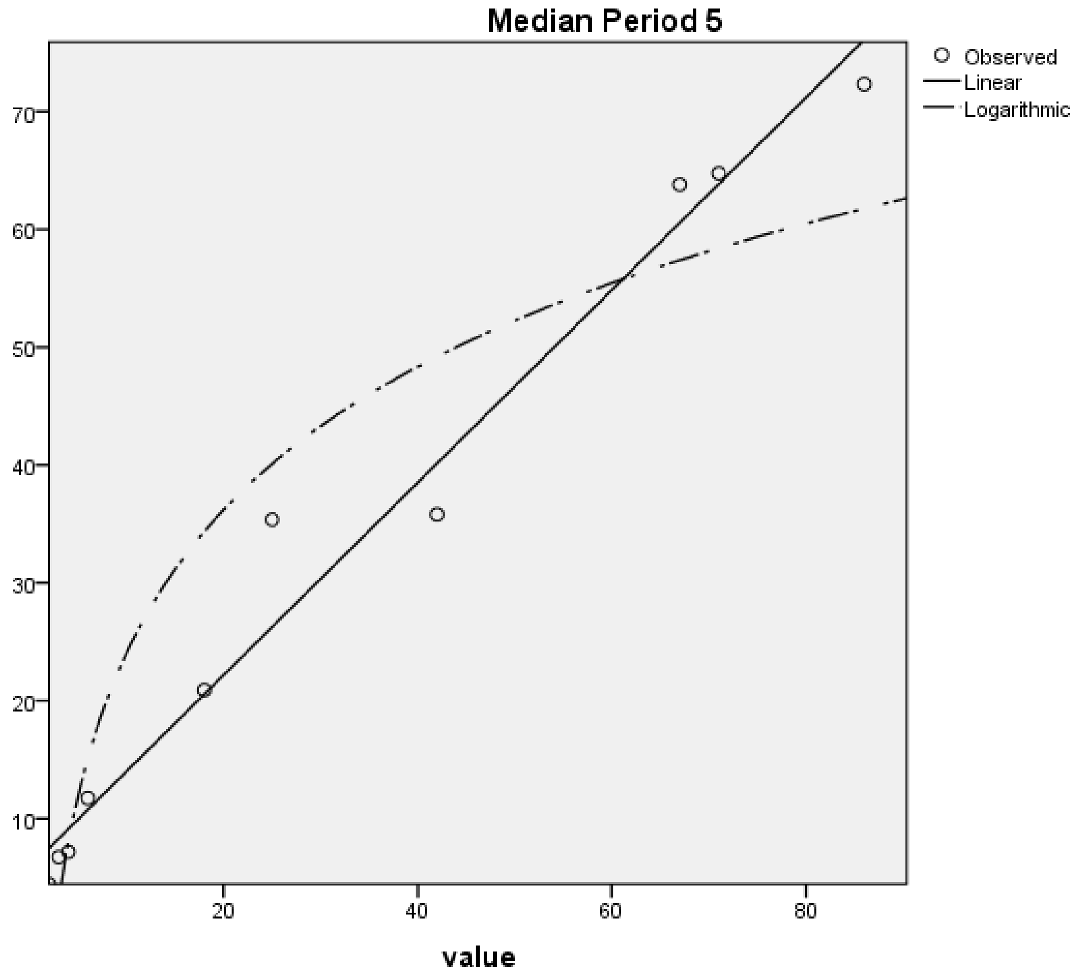


Figure 5: Representation in the middle of grade 2

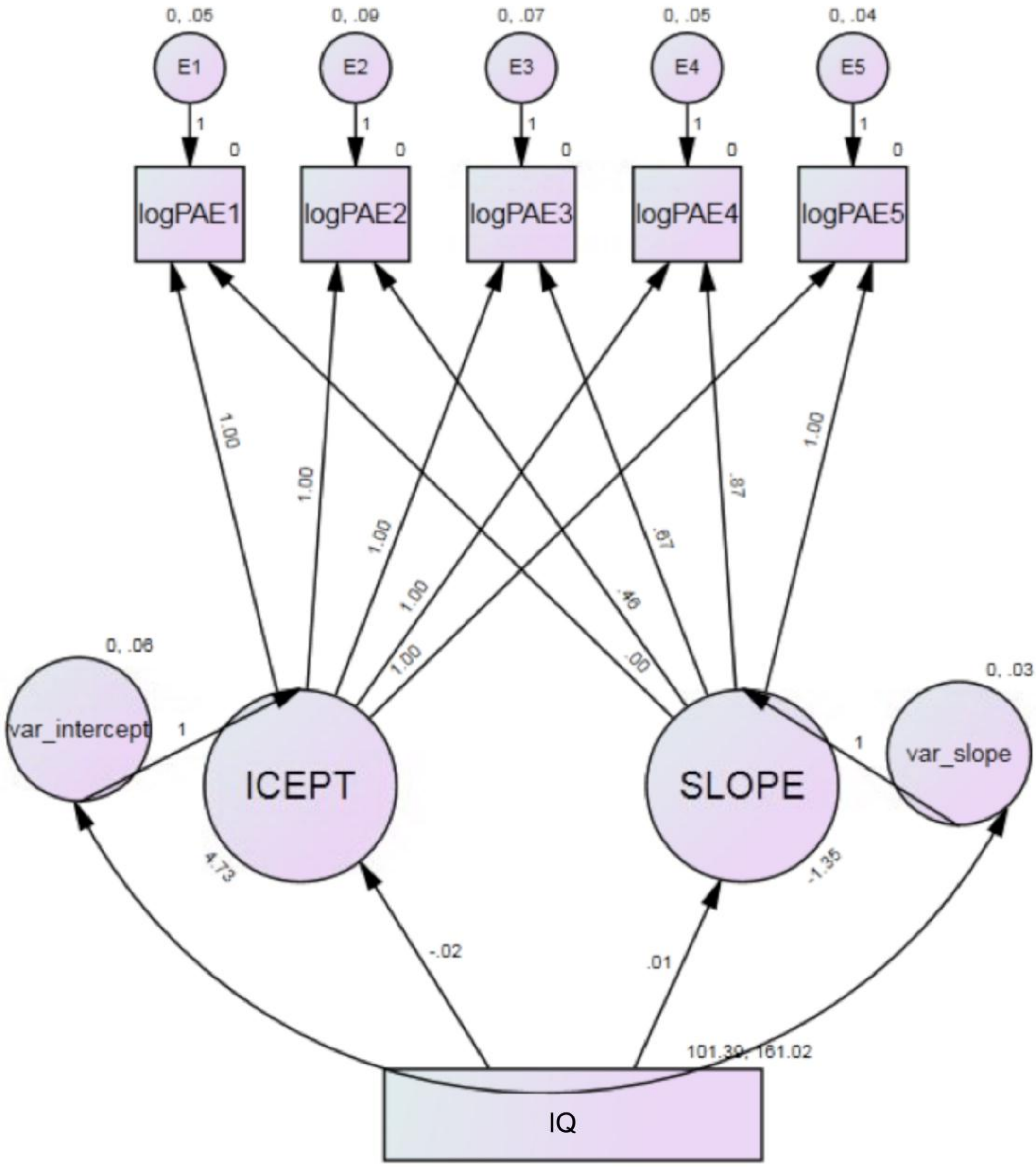


Figure 6: Latent Growth curve on estimation accuracy with intelligence as covariate

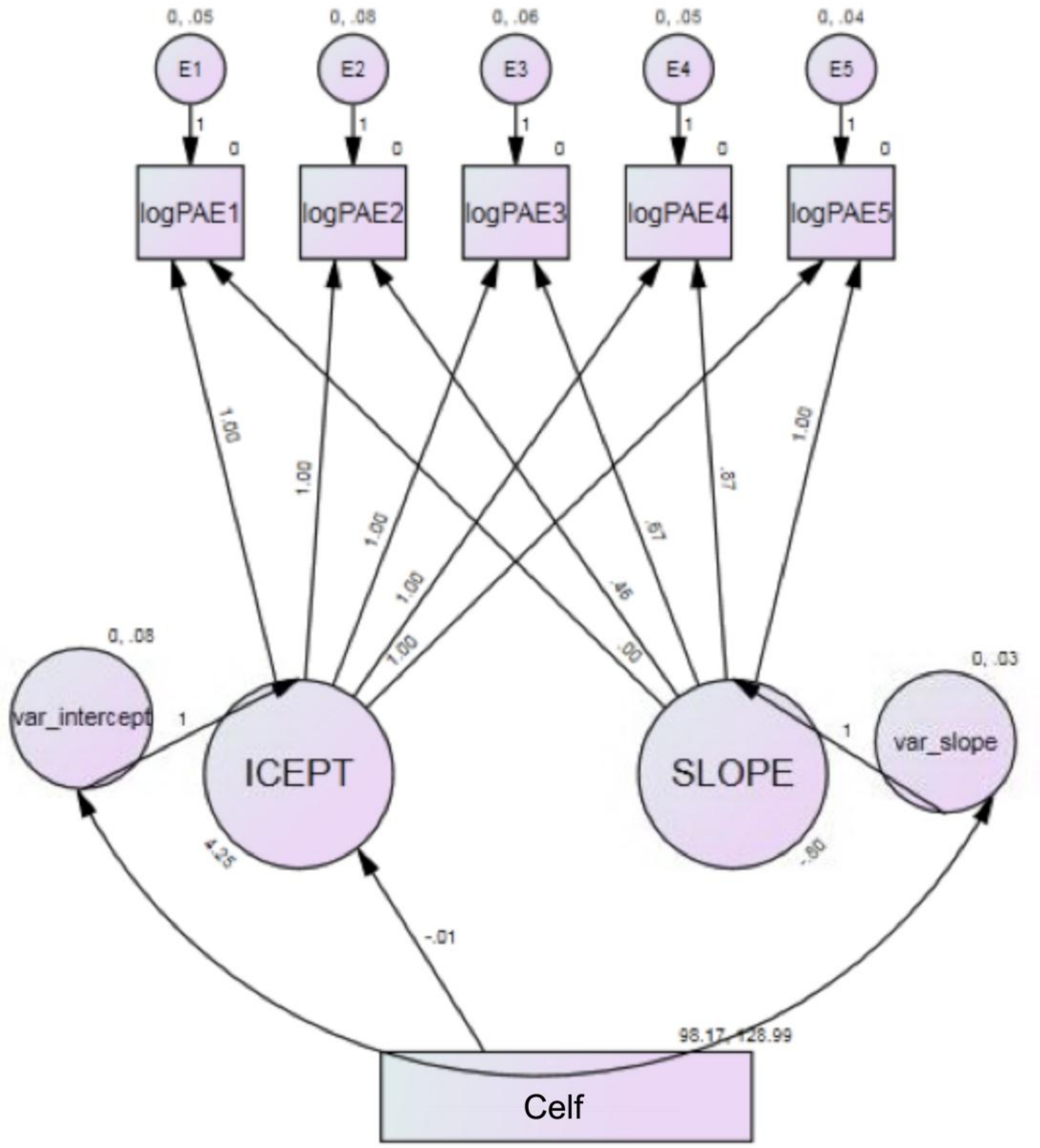


Figure 7: Latent Growth curve on estimation accuracy with language as covariate

Chapter 5

ENHANCING YOUNG CHILDREN'S ARITHMETIC SKILLS THROUGH NOT-INTENSIVE, COMPUTERISED KINDERGARTEN INTERVENTIONS: A RANDOMISED CONTROLLED STUDY.

Praet, M., & Desoete, A. (2014).
Teacher and teacher education, 39, 56-65.
http://dx.doi.org 10.1016/j.tate.2013.12.003

Abstract

Children in kindergarten were randomly assigned to adaptive computerised counting or comparison interventions, or to a business-as-usual control group. Children in both intervention groups, including children with poor calculation skills at the start of the intervention, performed better than controls in the posttest. However the effects of training held six months later in grade 1, playing serious counting games improving number knowledge and mental arithmetic performances, and playing serious comparison games, only enhanced the number knowledge proficiency in grade 1. The value of these short periods of intensive gaming in kindergarten are discussed as a look-ahead approach to enhance arithmetic proficiency.

1. Introduction

Several studies conducted in different countries over the past decades have consistently showed that difficulty with arithmetic is a common problem (e.g. Reigosa-Crespo et al., 2012), leading to children leaving school with insufficient skills (functionally illiterate in the domain of arithmetic), restricted employment options and manual, often low-paying, jobs (Dowker, 2005). While arithmetic achievement differs between countries, arithmetic difficulties seem to be a problem everywhere (Dowker, 2013; Opel, Zaman, Khanom, & Aboud, 2012; Parsons & Bynner, 2005).

Studies have reported that long before the onset of formal education large individual variation in engagement in the value of numbers and in early numerical skills existed among children (e.g., Aunio, Hautamäki, Sajaniemi, & Van Luit, 2009; Glauert, 2009; Glauert & Manches, 2013; National Research Council, 2009). It has also become increasingly clear that young children's early educational experiences have an impact on later outcomes (Sylvia, 2009), both in terms of educational achievement but also in the attitudes towards subjects (Glauert & Manches, 2013). Research has shown that early numerical skills are accurate predictors of later arithmetic achievement (Booth & Siegler, 2006; Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012; Krajewski & Schneider, 2009; Missall, Mercer, Martinez, & Casebeer, 2012; Vanderheyden, Broussard, Snyder, George, & Lafleur, 2011).

Early numerical skills

There is a growing body of research focusing on the possibility of stimulating the 'early numerical' or 'preparatory' skills or competences of young children (e.g. Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Greenes, Ginsubrg, & Balfanz, 2004; Kaufmann, Delazer, Pohs, Semenza, & Dowker, 2005; Morgan, Farkas, & Wu, 2009). In addition, the foundations of numeracy have been receiving ongoing attention. Researchers hope that by structured, early interventions supporting numeracy-related learning the problems might be reduced or even solved by providing at-risk children optimal opportunities to improve their knowledge and skills, preventing them from falling further behind (Clements & Scarama, 2011; DiPema et al., 2007; Fuchs, 2011; Ramey &

Ramey, 1998). Often, the aims of studies are to drastically reduce problems in learning outcomes (and the need for special education), as well as the negative, long-term effects, which occur when children leave school without the skills they need to function in their later life (Toll, 2013).

There are arguments for the claim that comparison and counting skills can be considered as foundations and as early numeracy skills that are associated with later proficiency in arithmetic skills.

Evidence for the importance of comparison stems from studies involving animals and young children estimating and comparing the value and number of objects and events (e.g. Ashcraft & Moore, 2012; Cantlon, 2012; Xu & Arriaga, 2007). Siegler and Ramani (2009), for example, found positive results for improving numerical representations by playing linear board games, based on the idea of Siegler and Booth (2004) that studying number line estimation is a useful means for learning about early numeracy because both require the approximation of magnitues (Toll, 2013). In addition, there is evidence for the relationship between arithmetic and children’s symbolic comparison skills ((De Smedt et al., 2013). Moreover, Mazzocco and colleagues (2008) and Desoete and colleagues (2012) revealed that children with mathematical learning disorders (MLD) made more comparison errors than peers without MLD.

Several studies provided evidence in favor of the importance of **counting** as an early numerical skill (Aunola et al., 2004; Cirino, 2011; Dunn, Matthews, & Dowrick, 2010; Fuchs et al., 2010; Torgenson et al., 2011**;** Van Luit & Schopman, 2000; Van Luit & Toll, 2013). Counting knowledge is thought to be a strong predictor of arithmetic abilities. Furthermore, counting might also be considered as a possible early screener for arithmetic problems (e.g. Stock, Desoete, & Roeyers, 2010). Dowker (2005) suggested that counting knowledge is a twofold concept as it consists of procedural and conceptual aspects. Procedural counting knowledge is defined as children’s ability to perform an arithmetic task (for example, being successful in determining the number of objects in an array (LeFevre et al., 2006)). One of the most important procedural aspects of counting is the number row (mastering the counting words sequence). This also includes the ability to easily count forward and backward. Conceptual knowledge on the other hand reflects the child’s understanding of procedural rules or whether a procedure is legitimate (LeFevre et al., 2006).

Mapping and arithmetic

Number line estimation tasks have been used to assess mapping skills in young children (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Kolkman, Kroesbergen, & Leseman, 2013; Slusser, Santiago, & Barth, 2013). The gain in precision with number line judgments has been documented in several studies (Siegler & Booth, 2004; Siegler & Opfer, 2003). In addition, below average performances on number representation tasks were documented in children with MLD (e.g. Mussolin, Mejias, & Noël, 2010; Piazza et al., 2010; Von Aster & Shalev, 2007). However, few studies have conducted causal evaluations. This study addresses this gap by investigating the effect of training arithmetic skills and on mapping proficiency.

Interventions in early numeracy skills

The importance and feasibility of pre-literacy interventions as a head-start is internationally recognised. Early studies with computer-assisted training showed positive results with just 4 hours of intensive gaming with grapheme-phoneme correspondences (Lyytinen et al., 2007). Clarke and colleagues (2011) revealed that early core arithmetic instruction is also needed for improvement. Wilson and Räsänen (2008) demonstrated that core interventions at an early age, provided in small groups or individually, had the greatest effect. This was in line with Aubrey (2013) and the US meta-analysis by Ramey and Ramey (1998) in concluding that interventions that begin earlier in development afforded greater benefits. In addition, it seemed to support explicit and systematic instruction (modelling and demonstrating) and use of visual representations (Witzel, Mink, & Riccomini, 2011).

Although early childhood education has been historically designed as child-

centred and nurturing, educational standards for early childhood teachers are rising with an intensification of teaching and a shift to program purposes even in young children (Bullough et al., 2014). Several **purposeful instructions** were found effective in the enhancement of early numeracy in young children (Bullough, Hall-Kenyoun, MacKay, & Marshall, 2014; Dobbs, Doctoroff, Fisher, & Arnold, 2006; Griffin, 2004; Jordan, Glutting, Dyson, Hassinger-Das & Irwin, 2012; Klein & Starkey, 2008; Kroesbergen & Van Luit, 2003; Van Luit

& Toll, 2013). Clements' study (1984) already revealed that classification and seriation were effective compared to the control condition, but that counting intervention had the highest power. In addition, Clements and Sarama (2007; 2009) developed and demonstrated the effectiveness of the 'Building Blocks' mathematics curriculum for young children. Number activities, such as counting, number recognition and number comparison, were specifically taught in a 26-week instructional program. This program looked to measure early mathematical knowledge and resulted in the experimental group reaching a higher level than the control group.

Other instruction materials are provided by Van de Rijt and Van Luit (1998) with the Additional Early Mathematics, (AEM), intervention program, for five year olds on eight aspects of preparatory arithmetic. They compared guided instruction and AEM, structured instruction and AEM with a control condition. Both AEM groups were effective on the posttest and delayed posttest, but the experimental groups did not differ from one another. This AEM training was also found to be effective in another study using AEM during 6 months (twice a week for 30 minutes; Van Luit & Schopman, 2000) revealing better results for comparison, the use of number names, counting and number knowledge in 5-7 year olds. Moreover, Van Luit and colleagues also developed 'The Road to Mathematics' (Van Luit & Toll, 2013) to teach low-performing kindergarteners, during 1.5 years in 90 thirty-minute sessions, a range of math language, reasoning skills, counting, structures, abstract symbols, measuring, number lines and simple calculations through structured activities thus simplifying the transition to math education in first grade. This program proved to be effective, even for kindergarteners with limited working memory skills. Griffin (2004) also demonstrated that early number sense could be developed through purposeful instruction. Their program 'Number Worlds' (20 minutes a day during 3 years) enhanced early numeracy.

In addition, several intervention studies were set up using '**games**'. Shaffer and Gee (2005) noticed that 'knowledge games', where students are asked to do things in a structured way (epistemic games), could serve education (Salamani Nodoushan, 2009). Educational games were also found to have a positive outcome for younger children and their learning. Siegler and Ramani (2008) developed 'The Great Race' and demonstrated better number comparison, number naming and counting skills in four year old boys with playing number board games that required children to spin a spinner and then move one or two numbers on the board until they reached 10. Playing these games, during 2 weeks of 4 sessions of 20 minutes each, resulted in improvements. The same effect was found in a larger study (Raman & Siegler, 2008). A similar study was conducted by Baroody, Eiland, and Thompson (2009) where kindergartners were instructed for 10 weeks, three times a week in small groups, using manipulatives and games focusing on basic number concepts, counting and numerical relations. In a second phase, children were randomly assigned to semistructured discovery learning, structured and explicit learning or haphazard practice. All groups made significant gains in an early math assessment, but it lacked a non-intervention control group to determine if the gains were due to the interventions. The value of number games with exercises in number comparison and counting to enhance early numeracy in kindergarten was also demonstrated by Whyte and Bull (2008). Furthermore, there is a bulk of evidence to suggest that targeted instruction can be effective (Bryant et al., 2011; Dowker & Sigley, 2010; Kaufmann et al., 2003; Ortega-Tudela & Gomèz-Arizat, 2006).

Moreover, **educational software** in the form of ‘**serious games**’ or ‘Computer Assisted Interventions' (CAI) has received growing interest (e.g. Niederhauser & Stoddart, 2001; Regtvoort, Zijlstra, & Van der Leij, 2013). There are already over 1000 apps on the iPad tagged for kindergarten (Glauert & Manches, 2013). International institutions, like the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2008), have advised and promoted the use of Information and Communication Technology (ICT) for teaching and learning (Rolando, Salvador, & Luz, 2013). Literature reviews showed that the use of ICT in teaching has a strong motivational effect on students (Lee et al., 2011). However, the introduction of technology in young children’s lives is not without controversy, with many public debates about the possible detrimental effect on children’s learning (Glauert & Mances, 2013). Although contradictory results have been found concerning the educational effectiveness of CAI games (Randel, Morris, Wetzel, & Whithall, 1992; Kroesbergen & Van Luit, 2003), several studies revealed CAI could be effective as an arithmetic support (Butterworth & Laurillard 2010; Räsänen et al., 2009). Wilson et al., (2006) developed the ‘Number Race’ for children aged 4 to 8; this open source game (freely available from http://sourceforge.net/projects/numberrace/) is based on the idea that number skills develop from approximate representations of magnitudes. These representations are connected to numbers with the aid of counting. The software trains children by presenting problems adapted to the performance level of the individual child. Children play games with all number formats (concrete sets, digits and number words), practice counting with numbers 1-40 and do additions and subtractions in the range 1-10. Playing the computer game during 5 weeks (4 days a week, sessions of 30 minutes) enhanced number comparison skills in grade 1 of elementary school. Comparing their pretest scores, the children improved and had also better counting skills after the training. The study by Brankaer et al. (2010) tried to replicate Wilson's study with training during four weeks (4 sessions of 10 minutes a week) including a control group. They did not find significant differences between the experimental and control group. Räsänen et al., (2009) also used the 'Number Race' during 3 weeks (10-15 minutes each day). They did find improvements in number comparison tasks. In addition, Räsänen et al. (2009) documented enhancement in number comparison with their 'Graphogame–Math' program used during 3 weeks (during 10-15 minutes each day) to learn the link between a number word and an Arabic number. This 'Graphogame-Math' game (openly downloadable from www.lukimat.fi) is based on the idea that learning the correspondences between small sets of objects and numbers helps the child to discover the relationships in the number system and arithmetic. According to Räsänen et al., (2009) the key difference between the 'Number Race' and 'Graphogame-Math' is that while the 'Number Race' stresses the importance of approximate comparison process, the 'Graphogame-Math' concentrates solely on exact numerosities and number symbols in the approach to numerical learning. The 'Number Race' game starts with the comparison of random dot patterns with large numerical difference, and the solution process does not require verbal mediation. The 'Graphogame-Math' starts with small sets of organised dot patterns, which are numerically close to each other, and the comparison process requires exact knowledge of the target quantity and its correspondence with the verbal label (Räsänen et al., 2009).

There is evidence that early numeracy interventions can also effectively improve the numeracy in **children at risk** (Aunio et al., 2009; Baker et al., 2002; Codding et al., 2009; Dunn, Matthews & Dowrick, 2010; Dyson et al., 2011; Jordan et al., 2012; Torgerson et al., 2011; Wright, Martland, & Stafford, 2006) and Jordan et al. (2009) provided evidence for the need for long (two to three year) interventions when aiming to enhance numeracy skills of these children at risk. However, even in some long intervention (Aunio et al., 2005) the effects faded six months after the intervention stopped. In addition, Dowker (2013) demonstrated that, in particular, individually targeted games and activities were effective for children with mathematical difficulties. Short (two 15-minute teaching sessions per week) interventions on 10 components (namely counting, reading and writing numbers, number comparison (hundreds, tens and units), ordinal numbers, word problems, translations, derived fact strategies, estimation and remembering number facts) worked better than similar amounts of attention on mathematics that was not targeted to a child's specific strengths and weakness. Children in the individual targeted intervention showed a mean ratio gain of 2.87 (SD = 2.89) meaning that they made more than twice as much progress as would be expected from the passage of time alone. Children who received matched time intervention showed a mean ratio gain of 1.47 (SD = 1.78), whereas the children receiving no intervention showed a mean ratio gain of 0.86 (SD = 3.17).

To conclude, several instructions were developed to enhance early numeracy skills in young children (e.g. Bloete, Lieffering, & Ouwehand, 2006; Wilson et al., 2006). However, most interventions were very intensive as they took about 6 to 9 months and sometimes even longer to be effective (Van de Rijt & Van Luit, 1998; Van Luit & Schopman, 2000). In addition, the majority of interventions focused on primary school children (Codding, Hilt-Panahon, & Benson, 2009; Kroesbergen & Van Luyt, 2003; Räsänen et al., 2009; Slavin, Lake & Groff, 2009; Templeton, Neel & Blood, 2008; Wilson et al., 2006). Moreover, it remained unclear whether one should target children's counting or comparison skills as specific components of early numeracy. Finally, although low performing children were found to benefit especially from long and intensive, supplemental instruction (Aunio et al., 2009; Dyson et al., 2011; Haseler, 2008; Jordan et al., 2009; 2012; Riccomini & Smith, 2011) it remained unclear if they also benefit from less intensive computerised interventions.

The present study

In the present investigation we report the findings of a randomised controlled trail with two short computerised conditions and a business-as-usual control group. We aimed to critically examine the effect of non-intensive, individualised but very short (8 sessions of 25 minutes) computerised interventions (using child-friendly computer games) in kindergarten with a pretest (wave 1), posttest (wave 2) and delayed posttest (wave 3) design.

The general aim of the present study was fourfold. Firstly, we investigated the modifiability of early numeracy in young children. We expected positive outcomes since early numeracy skills have been found to be trainable in other studies (e.g. Baker et al., 2002; Codding et al., 2009). However, previous studies were more intensive interventions whereas the present study examined if a shorter intervention (8 sessions in kindergarten) could also be effective. A counting and number comparison strategy approach is hypothesised as being capable of modifying kindergartens' early numerical skills in the posttest (hypothesis 1). We hypothesise no such improvement in the control conditions.

Secondly, we use two CAI groups – a counting and number comparison condition to explore to what extent those approaches differed and if one is more effective than the other as a computerised instruction variant. We were interested in the core components of kindergarten interventions on sustainable learning of mathematics in grade 1. We explored if both CAI were capable of improving the early numerical skills (wave 2 in kindergarten) and arithmetic achievement (wave 3 in grade 1) in young children (hypothesis 2).

Thirdly, we investigated the potential of the CAI on kindergartners with below average performance (< pc 25) in early calculation measures (wave 1). We explored the effect on the delayed posttest (wave 3) and expected that these at risk children would also benefit from the intervention (hypothesis 3).

Finally, we explored to what extent a kindergarten CAI was effective to change the mapping skills of young children. We expected less mapping errors when children reached better arithmetic skills (hypothesis 4).

2. Method

Participants

Participants were 132 (53% male) full-day kindergartners with a mean age of 68 months (*SD* = 4.01) from five schools in the same school district in Zele (Belgium). We obtained written parental consent for all children to participate in the study. The children had an average intelligence (TIQ = 101.39 (*SD* =12.73),

VIQ = 102.9 (*SD* =11.97), PIQ = 99.3 (*SD* =11.68) on the WPPSI. We calculated the Four Factor Index of Social Status (Hollinghead, 1975; Reynders et al., 2005) of the parents. Education and occupation scores were weighted and became a single score for each parent (range 13 to 66). Most parents had working and middle-class-socio-economic backgrounds. No significant differences were found between the intervention conditions. The Hollinghead index of the father and mother did not differ significantly between the three groups (F (4, 222) = 0.88; p = .478). Dutch was the only language spoken at home.

Measures

The study involved three waves of data collection. The first measurement took place while the children were in kindergarten (as pretest) before the children were randomly assigned to one of the three groups (see Table 2 and 4).

The second measurement took place just after the training (as posttest, see Table 3 and 4). In addition, the third test for grade 1 took place in January (as a delayed test, see Table 3). Children in Belgium enter elementary school aged 6 to 7.

Wave 1: pretest measures (assessed in kindergarten)

Children's early numerical achievement was measured (age 5 to 6) using three subtests of the TEDI-MATH (Grégoire et al., 2004). The TEDI-MATH has been used and tested for conceptual accuracy and clinical relevance in previous studies (e.g. Stock et al., 2010). The psychometric value was demonstrated on a sample of 550 Dutch speaking Belgian children from the second year of pre-school to the third grade of primary school.

Procedural knowledge of counting (see Table 2) was assessed with the TEDI-MATH 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 from 5 up to 9'). One point was given for a correct answer. The internal consistency of this task was good (Cronbach's alpha = .73).

The TEDI-MATH has proven to be a well validated (Desoete, 2006; 2007a & b) and reliable instrument, values for Cronbach's Alpha 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 till grade 1(Desoete & Grégoire, 2007) and on 240 children assessed in grade 1, 2 or 3 with TEDI-MATH and reassessed two years later with arithmetic tasks (Desoete, 2007). In addition the Flemish data were confirmed with similar data from the French speaking part of Belgium and France (Desoete, Roeyers, Schittekatte, & Grégoire, 2006).

Conceptual knowledge of counting was assessed with the TEDI-MATH using judgments about the validity of counting procedures. Children had to judge the count of linear and random patterns in drawings and counters. To assess the abstraction principle, children had to count different kinds of objects that were presented in a heap. Furthermore, a child counting a set of objects is asked 'how many objects are there in total?' or 'how many objects are there if you start counting from the leftmost object in the array?' When children have to count again to answer this it is considered to represent good procedural knowledge, but they prove a lack of understanding of counting principles so they earn no points. One point was given for a correct answer (e.g. 'you did not add objects so the number of objects has not changed'). The internal consistency of this task was good (Cronbach's Alpha = .85).

Finally, the calculation subtest of the TEDI-MATH was completed. This subtest consisted of series of simple arithmetic operations. The child was presented with six arithmetic operations as pictures (e.g. "here you see two red balloons and three blue balloons, how many balloons are there together?"). Cronbach's alpha was .84.

All children were also tested on their mapping skills (as an independent measure) with a number-to-position horizontal number line estimation task. This Number Line Estimation (NLE) task used a 0-100 interval, in line with Berteletti and colleagues (2010) and Booth and Siegler (2006). The task included three exercise trials and 30 test trials 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 by Dehaene, Izard and Piazza (2005), meaning that in half the trials, the dot size was constant, and in the other half, the size of the total occupied area of the dots was constant. The number line had a lower and upper anchor, but no periodically marked scale. No feedback was given to participants regarding the accuracy of their marks. The Percentage Absolute Error (PAE) was calculated per child as a measure of children's mapping skills, following a formula by Siegler and Booth (2004).

In addition, intelligence was assessed with the WIPPSI-NL (Wechsler et al., 2002). Children completed the three core verbal tests (information, vocabulary and word reasoning) and the three performal tests (block patterns, Matrix reasoning and concept drawing). We also took the item substitution into account as being a core-subtest.

Wave 2: posttest measure (assessed in kindergarten)

The calculation subtest of the TEDI-MATH after the intervention, at the end of kindergarten (wave 2).

Wave 3: Follow-up measure of arithmetic in grade 1 (assessed in January)

In grade 1 (wave 3), all children completed the 0-100 number line estimation task and the Kortrijk Arithmetic Test Revised(Kortrijkse Rekentest Revision, KRT-R, Baudonck et al., 2006). The Kortrijk Arithmetic Test Revision (Kortrijkse Rekentest Revision, KRT-R; Baudonck et al., 2006) is a standardised test of arithmetical achievement which requires children to solve 30 mental arithmetic (e.g. '16-12 =_') and 30 number knowledge tasks (e.g. '1 more than 3 is _'). The KRT-R is frequently used in Flemish education as a measure of arithmetic achievement. 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 alpha) of .50 and .92 respectively were found for first grade.

Procedure

Parents received a letter explaining the research and submitted informed consent in order for their children to participate. All children were assessed individually, outside the classroom setting. The investigators received training in the assessment and interpretation of the tests. The test protocols were not included in the analyses of this study. All items were entered, on an item-by-item basis, into SPSS. A second scorer independently re-entered all protocols with 100% agreement.

Within each school and kindergarten class, children were randomly assigned to participate in the counting group (playing serious counting games), number comparison group (playing serious comparison games), or a business-as-usual control group; such that children from each classroom were assigned equally to the three groups (e.g. if three students from a classroom participated, they were assigned to each of the three groups). The inclusion of three groups was important to ensure that any treatment effect obtained by the counting or comparison group could be attributed to the counting CAI (in counting group), comparison CAI (in comparison group), rather than to other factors such as motivation quantitative relation experiences (in comparison and counting group) or just getting older (in all groups, also in the control group; see Table 1). In

Table 1

Different 'serious games' compared

Intervention Model	Serious Counting games	Serious Comparison Games	No arithmetic games Control Group
Counting instruction	+	-	-
Comparison instruction	-	+	-
Computerised games	+	+	+
Additional interest by researchers	+	+	+

addition, trainers and teachers were double-blinded to the research questions in this study.

The CAI interventions (serious games) took place in nine individual computerised sessions in a separate classroom during 5 weeks, 25 minutes each time. Multiple treatments were performed at each school. Each session consisted of solving problems in accordance with the instructions given in the program (computer game). Four paraprofessionals were trained to teach both CAI instruction variants (number comparison and counting intervention) and to take the pretest, posttest and delayed posttest measures of the children. The paraprofessionals were skilled therapists with experience with children with mathematical learning problems. Initial paraprofessional training took place one month prior to the start of the interventions. Systematic ongoing supervision and training was provided during the interventions. Throughout the interventions and across paraprofessionals, treatment integrity was very high and there was a 100% fidelity to essential instruction practices.

Each of the **comparison sessions** involved a non-intensive, but individualised and adaptive Computer Assisted Instruction (CAI) for number comparison or serious game without counting instruction. Children learned to focus on number and not on size. They learned to compare the number of animals, by pointing the mouse to the group of animals that had the greatest quantity, making abstraction of the size of animals. In addition, children had to compare two different kinds of stimuli (animals/dots). There were exercises with organised and non-organised objects. Moreover, children learned to compare visual and auditory quantities and to compare quantities (dots) with number words or Arabic numbers and number words . All children got a basic program with additional exercises on the components they experienced as difficult, since the CAI had an adaptive structure. Children learned by playing the game. The game incorporated a dynamic element since it adapted to the child's own level of ability and set further levels in accordance with this ability. This prevented frustration, while positive feedback sustained the child's interest in playing for sufficient time for learning to be established. Children were able to play the game by themselves, without teachers having to help them.

In the experimental Computer Assistant Instruction (CAI) for **counting,** children did computerised exercises (playing a computer game) on procedural and conceptual counting knowledge. They played games for learning to count synchronously and learned to count without mistakes, thus experiencing the cardinality principle. Clicking on a symbol generated a quantity of that symbol with an upper bound of 6. The child was asked to count and register it by tapping the number on the keyboard. Auditory feedback was given. Children were asked: "how many animals are there?" or "how many can bark?" while there were objects, plants and animals on the screen. The instruction was read aloud and an answer was given by tapping the number of stars. Visual feedback was provided by a happy or a sad smiley. Auditory feedback was given in the form of a sob when they made a mistake or applause when they succeeded. There were exercises with the accent on adding, subtracting and leaving only a certain quantity .All children basically started at the same level. As CAI has an adaptive structure, additional exercises were foreseen for children who experienced difficulties. The game adapted to the child's own level of ability and set further levels in accordance with this ability. Learning was fun and the children were able to play it alone.

Our control group was active, to prevent the Hawthorne effect (positive effects due to extra attention in de CAI-groups). Control subjects (control group) received the same amount of instruction time as the children in the two other conditions. However, instead of counting or comparison instruction, the control group received nine enjoyable sessions of regular kindergarten activities (intervention as usual and had the opportunity to do some non-math games on the computer).

3. Results

Preliminary comparisons (wave 1)

The three groups were matched on pretest kindergarten skills. No significant differences were found ($F\ (2,128) = 0.05;\ p = .949$) for kindergarten calculation skills tested with the TEDI-MATH. Moreover, the groups did not differ on the WPPSI-III ($F\ (2,128) = 0.73;\ p = .484$). In addition, preliminary analyses with gender (($F\ (1,129) = 0.05;\ p = .826$) in the model as between subject variable yielded no significant main effects or interactions across all the measures. Thus gender was not considered further in the analyses. For *M* and *SD* on the pretest measures see Table 2

Treatment effects of CAI on arithmetic (wave 2 and 3)

In order to investigate the research hypotheses on the modifiability of early numerical skills (hypothesis 1), as well as on the value of counting versus number comparison, we included instruction on learning arithmetic skills (hypothesis 2), a posttest (wave 2) and a delayed posttest (wave 3). Dependent measures were analyzed by an univariate analysis of variance (ANOVA) or multivariate analysis of conditional variance (MANOVA) (counting CAI, number comparison CAI, control condition) as a group. Each (M)ANOVA determined whether there was a significance in the three conditions, when compared to the dependent measure at pretesting, posttesting and delayed

posttesting. In addition, posthoc tests were performed on the posttest and delayed posttest scores using an appropriate posthoc procedure (using Tukey if equal variance could be assumed from the Levene test and Tamhane if equal variance could not be assumed from the Levene test). In addition, we calculated the observed power and effect sizes.

Table 2

Means and Standard Deviations of the pretest skills in kindergarten

	Control group *N*= 49	Counting games *N*=44	Comparison games *N*=39	*F* (2,129)=.
Mean age	67.67	68.50	68.28	0.58
	(4.05)	*(3.83)*	*(3.96)*	
SES father	37.74	34.48	38,21	1.06
	(10.18)	*(12.56)*	*(11,19)*	
SES mother	38.55	38.67	41,18	0.01
	(11.08)	*(11.29)*	*(10,58)*	
VIQ	101.57	102.50	103,67	0.31
	(11.11)	*(12.68)*	*(12,42)*	
PIQ	96.86	99.41	101.72	1.90
	(12.83)	*(10.10)*	*(11.79)*	
Procedural Counting	6.31	6.30	6.49	0.17
	(1.58)	*(1.74)*	*(1.71)*	
Conceptual Counting	9.98	9.75	10,41	0.52
	(3.07)	*(3.38)*	*(2.31)*	
Arithmetic	7.39	7.55	7.64	0.03
(kindergarten)	*(5.16)*	*(5.55)*	*(4.94)*	

Significant differences were found (*F* (2,129) = 19.70*; p* <.001, $ή^2$ =.23) between the groups in calculation skills (wave 2) after the intervention took place. Children in the counting condition did better than children in the number comparison intervention. Children in both CAI groups had significant higher calculation scores than children in the control group (see Table 3).

In addition, the MANOVA using number knowledge and mental arithmetic assessed in grade 1 (wave 3), as dependent variable, was significant on the multivariate level (*F* (4, 250) = 4.03; *p* =.003; $\eta^2 = .06$). Significant differences were found between the groups for number knowledge (*F* (2,125) = 6.42; *p* =.002, η^2= .09) and mental arithmetic (*F* (2, 125) = 6.16; *p* = .003; $\eta^2 = .09$). Table 3 provides *M*, *SD* and posthoc analyses between the groups. Both CAI groups had a better number knowledge compared to the control group. There was a significant difference between the CAI on counting and the control group for mental arithmetic.

Table 3

Arithmetic skills in kindergarten and grade 1

	Control group M *(SD)*	Counting games M *(SD)*	Comparison games M *(SD)*	
Posttest (Kindergarten) Arithmetic	8.65(*c*) *(3.38)*	12.85(*a*) *(3.12)*	10.86(*b*) *(3.12)*	F (2, 129) = 19.70*
Delayed test (grade 1) Number knowledge	19.22(*b*) *(5.94)*	22.58(*a*) *(4.28)*	22.34(*a*) *(4.40)*	F (2, 125) = 6.42*
Delayed test (grade 1) Mental Arithmetic	18.11(*b*) *(6.60)*	22.30(*a*) *(4.98)*	20.66 *(5.40)*	F (2, 125) = 6.16*

*p ≤.005, *ab* = posthoc indexes $p \leq .005$;

Treatment effects of CAI on low-performing children (in wave 3)

There was no significant interaction- effect (F (4, 242) = 1.02; p = .400) for intervention group (counting, comparison, control) x performance (poor, average). This means that both groups of children (low and average performers) benefitted from the CAI in supporting development of their early numerical skills.

Treatment effects of CAI on low-performing children (in wave 3)

In wave 3 (F (2, 121) = 1.02; p = .400) there were no significant interaction effects. This means that both groups of children (low and average performers) benefitted from the CAI in supporting development of their early numerical skills.

Treatment effects of the CAI on mapping skills (wave 3)

As expected, children did not differ on mapping skills (F (2, 127) = 0.83; p = .436) before the intervention (in wave 1). However, after the CAI (in wave 3), the three groups did not differ significantly on mapping performances either (F (2, 119) = 0.61; p = .547), meaning that the CAI did not enhance mapping skills. Table 4 provides raw score means and standard deviations for the Percentage of Absolute Error (PAE) on the 0-100 number line estimation task which was separated into pretest (wave 1) and delayed posttest (wave 3).

4. Discussion

According to Shaffer and Gee (2005), the foundations for lifelong learning should be laid in kindergarten and before. The school curriculum should include a wide range of skills and abilities as islands of expertise preparing young children to engage with complex and deep learning from the start.

There seems to be some key steps in developing arithmetic abilities with early arithmetic abilities as strong predictors for later school achievement (e.g.

Geary, 2011; Jordan et al., 2012; Missall et al., 2012; Stock et al., 2010). Additionally studies have reported large individual differences among children even before the onset of formal education (e.g. Aunio et al., 2009). If markers for the atypical arithmetic development can be recognised, perhaps CAI can help prevent children at risk from falling further behind. The central question behind this study was whether or not a not-intensive Computer Assistant Intervention (CAI) in kindergarten can engage children in the value of numbers and facilitate instruction of arithmetic in grade 1, as already found in older children (Räsänen et al., 2009; Wilson et al., 2006). Indeed, it can. Children in this study were randomly assigned to the experimental number comparison, experimental counting or control condition. The adaptive CAI on number comparison (using asymbolic material, number words and Arabic numbers) or counting (using number words and Arabic Numbers to count) took place at the end of kindergarten. Both non-intensive yet individualised experimental interventions had a sustained effect on arithmetic which was noticeable in the delayed posttest, taken six months after the training while the children were in grade 1. Children in both experimental groups performed better than the control group (taking into account that the groups were matched on their pretest score) in number knowledge. In addition, the counting group also had better mental arithmetic skills than the comparison and control groups. The findings demonstrate that digital technology presented new opportunities for learning and exploring early numerical concepts and sharpened the actual learning process in young children. Even non-intensive and computerised adaptive interventions in pre-school can enhance early numeracy in young children with a delayed effect on arithmetic performances in grade 1. Waiting till grade 1 to intervene, when arithmetic difficulties become persistent, seems a waste of valuable (instruction) time.

Table 4

Mapping skills separated by pretest and delayed posttest (Grade 1).

	Control group M *(SD)*	Counting games M *(SD)*	Comparison games M *(SD)*	
Pretest (kindergarten) PAE	*25.22 (9.14)*	*25.98 (8.96)*	*23.51 (7.77)*	*F* (2, 129) = 0.86
Delayed test (grade 1) PAE	*16.64 (6.73)*	*18.29 (8.05)*	*18.15 (7.44)*	*F* (2, 125) = 0.68

*p ≤ 05, PAE=Percentage Absolute Error on the 0-100 number line estimation task

However, when looking for key components to see whether counting or comparing is the most effective, there was a slight difference between the outcomes of the two serious games (counting and comparing CAI). They both had an impact on number knowledge, but playing educational counting games also had an impact on mental arithmetic. Thus, our study specifically revealed the value of adaptive computerised counting intervention in kindergarten as a look-ahead approach to enhance arithmetic proficiency in grade 1.

Furthermore, this study revealed, in line with Dowker (2013) and Ramani and Siegler (2008; 2011), that early numeracy can be stimulated in kindergarten, even in low-performers, with a sustained effect on arithmetic in grade 1. This is good news for children at risk of developing mathematical learning difficulties. Playing educational counting games (see also Wilson et al., 2006 and Räsänen et al., 2009) might create a buffer against poor arithmetic outcomes. In line with Sylvia (2009), we found that young children's early educational experiences might have an impact on later outcomes in terms of educational achievement and, perhaps, also on attitudes towards mathematics. Teachers and teacher educators should understand the importance of a rich environment with opportunities for children to explore and make sense of numerical experiences and know that they can accelerate early numeracy development in kindergartners with educational games. Dawson (2003) revealed that teachers tend to underestimate the capabilities of young children when it comes to mathematics and may not have the knowledge to focus on important mathematical experiences. Therefore, the finding from this study, that it is possible to use computer software in an entertaining game-like format for providing learning experiences with an effect on later arithmetic proficiency, is an important finding. The discovery of the key role of counting reminds us that, in particular, exposure to counting games seems applicable in kindergarten. Additional research seems to indicate that evaluating such early interventions in high-risk children (siblings with an enhanced risk of developing MLD (Shalev et al., 2001)) can also boost their numerical development and prevent them from falling behind, avoiding math or even develop math anxieties. In addition, the counting-CAI might have potential uses in response-to-intervention programs for identifying children with genuine MLD (non-responders) versus children with learning difficulties (responders) related to inadequate instructional or parental support.

Finally, up untill now, no intervention studies have been used to study the relationship between mapping, assessed with a number line estimation paradigm, and arithmetic performance in young children. Although both experimental groups made gains in arithmetic compared to controls, the groups playing serious games did not outperform the controls in the area of mapping. Thus, our data demonstrated that arithmetic skills could be enhanced without mapping skills growing at the same time, thus questioning the causal relationship between number line estimation and arithmetic in young children.

The main, practical implication of this study concerns the importance of counting skills in the development of arithmetic skills. The findings of this study inform diagnostic procedures to focus specifically on counting (as symbolic number skill) in kindergarten. Moreover, our study revealed the value of adaptive serious games as a didactic method and look-ahead approach to enhance learning. We demonstrated that an intensification of teaching in kindergarten, by using adaptive serious games in regular kindergarten classes, can provide children with playful, immediate and continuous feedback, as well as repetitive learning, and can be used as preventive support for low early numerical skills. These findings might contribute to knowledge of the subject matter, the pedagogical content knowledge and the attitude of teachers and teacher educators towards games and arithmetic. In addition, using these serious games at home might also be a promising way of assisting high-risk children with ‘additional educational needs’. Adaptive games as a core part of the curriculum and preventive support in regular kindergarten classes might prevent a waste of valuable instruction time and, therefore, also contribute to the realisation of inclusive education in elementary school.

These results should be interpreted with care since there are some limitations to the present study. We only assessed a small group of kindergarten children. Obviously, sample size is not a problem with significant differences (such as the calculation and arithmetic skills in wave 2 and 3). However, when analyses have insufficient power and are not significant (such as the analysis on mapping skills in wave 2 and mental arithmetic in wave 3), a risk of type 2 or Beta mistakes (concluding from the cohort that there were no differences, although in reality there were differences in the population) could not be excluded. Additional research with larger groups of participants comparing both CAIs is indicated. Moreover, it is possible that using a multi-method design with symbolic comparison, as well as number line estimation tasks as mapping tests, could increase the credibility of the study. Furthermore, context variables, such as home and teacher content knowledge and expectations (e.g., Brady & Woolfson, 2008; Buldu, 2010; Depaepe, Verschaffel, & Kelchermans, 2013; Flouri, 2006; Rubie-Davies, 2010) and parental involvement (e.g. Reusser, 2000), should be included. Controlling the factors that might harm the study, may achieve a more complete overview of the effect of the interventions on these children's development. These limitations indicate that only a part of the picture was investigated, so additional studies should focus on these aspects.

In addition, although Shaffer and Gee (2005) stressed the importance of kindergarten for lifelong learning, engaging children with complex and deep learning from the start, we should respect the nature of young children and stress that kindergarten is a time for learning, not for training. Moreover, it is important to notice that kindergarten classrooms are understaffed, some countries have 22 kindergarten children in a classroom, so teachers often feel overwhelmed by what is required of them (Bullough et al., 2014) experiencing difficulties providing inquiry-based education (Alake-Tuenter, Biemans, Tobi, & Mulder, 2013). However, it is important to notice that in line with the study by Lyytinen et al. (2007), our study demonstrated positive results in less than 5 hours of intensive gaming. Perhaps older children ('ICT'-friends from grade 5) or parents (a 'computer'-parent) might help children in kindergarten at regular moments in the week to start using games. Serious games are, however, fun, intuitive and easy to play. Children in this study were able to play them alone or with very little instruction. Thus, games might not hinder the teacher, but allow them to focus on other children while being sure that the children playing the adaptive games 'learned' and enjoyed connecting new knowledge to prior knowledge.

Kindergarten teachers focusing on numbers and on intensified stimulation of children to count can enhance young children's numerical development. In addition, classroom teachers should be aware that waiting for non-responsiveness to intervention in grade 1 is a waste of time and a short period of intense gaming with counting games in kindergarten might be of use to fill the gap between children at-risk and children spontaneously learning.

References

Alake-Tuenter, E., Biemans, H.J.A., Tobi, H., & Mulder, M. (2013). Inquiry-based science teaching competence of primary school teachers: A Delphi study. *Teacher and Teacher Education, 35(2013)*, 13-24. http://dx.doi.org/10.1018/j.tate.2013.04.013

Ashcraft, M.H., & Moore, A.M. (2012). Cognitive processes of numerical estimation in children. *Journal of Experimental Child Psychology, 111(2)*, 246-267. http://dx.doi.org/10.1016/j.jecp.2011.08.005

Aubrey, C. (2013). *Mathematical and thinking skills interventions for low performing children*. Discussion paper. EARLI conference August 27th Munchen.

Aunio, P., Hautamäki, J., & Van Luit, J.E.H. (2005). Mathematical thinking intervention programs for preschool children with normal and low number sense. *European Journal of Special needs Education, 20(4),* 131-146. http://dx.doi.org/10.1080/08856250500055578

Aunio, P., Hautamäki, J., Sajaniemi, N., & Van Luit, J.E.H. (2009). Early numeracy in low-performing young children. *British Educational Research Journal, 35(1)*, 25-46. http://dx.doi.org/10.1080/01411920802041822

Aunola, K., Leskinen, E., Lerkkanen, M. K., & Nurmi, J. E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96 (4)*, 699–713. http://dx.doi.org/10.1037/0022-0663.96.4.699

Baker, S. , Gersten, R., & Lee, D. (2002). A synthesis of empirical research on teaching mathematics to low-achieving students. *The Elementary School Journal*, 103(1), 45-74. http://dx.doi.org/10.1086/499715

Baroody, A.J., Eiland, M., & Thompson, B. (2009). Fostering at-risk preschoolers' number sense. *Early Education and Development, 20(1),* 80-128. http://dx.doi.org/10.1080/10409280802206619

Baudonck, M., Debusschere, A., Dewulf, B., Samyn, F., Vercaemst, V., & Desoete, A. (2006). *Kortrijke Rekentest Revisie(KRT-R).* Kortrijk: Revalidatiecentrum Overleie.

Berteletti, I., Piazza, M., Dehaene S., & Zorzi, M. (2010). Numerical Estimation in Preschoolers. *Developmental Psychology, 46(2)*, 545-551. http://dx.doi.org/10.1037/a0017887

Bloete, A.W., Lieffering, L.M., & Ouwehand, K. (2006). The development of many-to – one counting in 4-year-old children. *Cognitive Development, 21(3),* 332-348. http://dx.doi.org/10.1016/j.cogdev.2005.10.002

Booth, J.L., & Siegler, R.S. (2006) Developmental and individual differences in pure numerical estimation. *Developmental Psychology, 42(1),* 189-201. http://dx.doi.org/10.1037/0012-1649.41.6.189

Brady, K., & Woolfson, L.(2008). What teacher factors influence their attributions for children's difficulties in learning? *British Journal of Educational Psychology, 78(4)*, 527 -544. http://dx.doi.org/10.1348/000709907X268570

Brankaer, C., Ghesquière, P., & De Smedt, B. (2010). Onderzoek naar het effect van de Getallenrace: een computerprogramma om getalgevoel te stimuleren bij kinderen met rekenproblemen *[Study on the effect of the number race: a computerized program to stimulate the number sense in children with arithmetic problems]*. Unpublished master thesis University Louvain: Belgium. mdkey: 9de58b91411550fe3dffff5fe0d9da7b

Bryant, D.P., Bryant, B.R., Roberts, G., Vaughn, S., Pfannenstiel, K.H., Porterfield, J., & Gersten, R. (2011). Early Numeracy Intervention Program for First-Grade Students With Mathematics, *Exceptional Children, 78(1), 7-23*

Buldi, M. (2010). Making learning visible in kindergarten classrooms: Pedagogical documentation as a formative assessment technique. *Teaching and Teacher Education, 26(8),* 1439-1449. http://dx.doi.org/10.1016/j.tate.2010.05.003

Bullough, R.V., Hall-Kenyon, K.M., MacKay, K.L., Marshall, E.E. (2014). Head start and the intensification of teaching in early childhood education. *Teaching and Teacher Education, 37(2014)*, 55-63. http://dx.doi.org/10.1016/j.tate.2013.09.006

Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscalculia: identification and intervention. *ZDM The international Journal on Mathematics Education, 42(6),* 527-539. http://dx.doi.org/10.1007/s11858-010-0267-4.

Cantlon, J.F. (2012). Math, monkeys and the developing brain, *PNAS*, 109 suppl. 1, 10725-10732. http://dx.doi.org/10.1073/pnas.1201893109

Cirino, P.T. (2011). The interrelationships of mathematical precursors in kindergarten. *Journal of Experimental Child Psychology, 108(4)*, 713-733. http://dx.doi.org/10.1016/j.jecp.2010.11.004

Clarke, B., Doabler, C.T., Baker, S.K., Fien H., Jungjohann, K., & Strand Cary, M. (2011). *Pursuing instructional coherence* in R. Gersten & R. Newman-Gonchar (Eds). Understanding RTI in mathematics. Proven methods and applications (p.49-64) Baltimore, ML: Brookes

Clements, D.H. (1984). Training effects on the development and generalization of Piagetian logical Operations and knowledge of number. *Journal of Educational Psychology*, 76(5), 766-776. http://dx.doi.org/10.1037/0022-0663.76.5.766

Clements, D.H., & Sarama, J. (2004). Learning trajectories in mathematics education. *Mathematical thinking and learning,* 6(2), 81-89. http://dx.doi.org/10.1207/s15327833mtl0602_1

Clements, D.H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum. *American Educational Research Journal*, *45(2),* 443-494. http://dx.doi.org/10.3102/0002831207312908

Clements, D.H., & Sarama, J. (2011). Early childhood mathematics intervention.Science, 333(6045), 968-970. http://dx.doi.org/10.1126/science.1204537

Clements, D.H., & Sarama, J. (2009). *Learning and teaching early math: The learning trajectories approach.* New York, NY: Routledge.

Clements, D.H., Sarama, J., Splitler, M.E., Lange, A.A., & Wolfe, C.B. (2011). Mathematics learning by young children in an intervention based on learning trajectories: A large-scale-cluster randomized trial. *Journal of Research in Mathematics Education, 42 (2),* 127-168. http://www.jstor.org/stable/10.5951/jresematheduc.42.2.0127

Codding, R.S., Hilt-Panahon, A., Panahon, C.J., & Benson, J.L. (2009). Addressing mathematics computation problems: A review of simple and moderate intensity interventions. *Education and treatment of Children, 32(2)*, 279-312. http://dx.doi.org/10.1353/etc.0.0053

Dawson, R. (2003). Early math strategy: the report of the expert panel on early math in Ontario. Ontario, Ontario Ministery of Education.

Dehaene, S., Izard, V., & Piazza, M. (2005). Control over non-numerical parameters in numerosity experiments. Unpublished manuscript (available at http://www.unicog.org/…/DocumentationDotsGeneration.doc).

Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge : A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education, 34* (August 2013) 12-25. http://dx.doi.org/10.1016/j.tate.2013.03.001

De Smedt, B., Noël, M.P., Gilmore, C., & Ansari, D. (2013). How do symbolic and non-symbolic numerical magnitude processing skills relate to individual differences in children's mathematical skills? A review of evidence from brain and behavior. *Trends in Neuroscience and Education 2(2),* 48-55 http://dx.doi.org/10.1016/j.tine.2013.06.001

Desoete, A., Ceulemans, A., De Weerdt, F., & Pieters, S. (2012). Can we predict mathematical learning disabilities from symbolic and non-symbolic comparison tasks in kindergarten? Findings from a longitudinal study. *British Journal of Educational Psychology, 82(1)*, 64-81.http://dx.doi.org/10.1348/2044-8279.002002

Desoete, A. (2006). Validiteitsonderzoek met de TEDI-MATH [Validity research on the TEDI-MATH]. *Diagnostiek-wijzer, 9,* 140-157.

Desoete, A. (2007a). Students with mathematical disabilities in Belgium: from definition, classification and assessment to STICORDI devices. (pp. 181-222). In T.E. Scruggs & M.A. Mastropieri (Eds.), Advances in Learning and Behavioral Disabilities, Vol. 20. International Perspectives Amsterdam & Oxford: Elsevier Press.

Desoete, A. (2007b). De TEDI-MATH. De plaats van de Tedi-Math in de diagnostiek van dyscalculie in Vlaanderen. [The value of the Tedi-Math in the assessment of mathematical learning disabilities in Flanders]. Caleidoscoop, 19 (6), 6-19.

Desoete, A., Roeyers, H., Schittekatte, M., & Grégoire, J. (2006). Dyscalculie-gevoelige kennis en vaardigheden in het basisonderwijs in Vlaanderen, Wallonië en Frankrijk. [Dyscalculia-sensitive knowledge and skills in elementary education in the Flemish and French speaking part of Belgium and in France]. Pedagogische Studieën, 83, 105- 121

DiPema , J.C., Lei, P.W., & Reid, E.E. (2007). Kindergarten predictors of mathematical growth in the primary grades: an investigation using the early childhood longitudinal study-Kindergarten cohort. *Journal of Educational Psychology, 99(2)*, 369-379. http://dx.doi.org/10.1037/0022-0663.99.2.369

Dobbs, J., Doctoroff, G.L., Fisher, P.H., & Arnold, D.H. (2006). The association between preschool children's socio-emotional functioning and their mathematic skills. *Journal of Applied Developmental Psychology, 27(2)*, 97-108. http://dx.doi.org/10.1016/j.apppdev.2005.12.008

Dyson, N. I., Jordan, N. C., & Glutting, J. (2011). A number sense intervention for low-income kindergartners at risk for math difficulties. *Journal of Learning Disabilities,* 46(2) 166-218Advance online publication. http://dx.doi.org/10.1177/0022219411410233

Dowker, A. (2005). Early identification and intervention for students with mathematical difficulties. *Journal of Learning Disabilities, 38(4)*, 324-332. http://dx.doi.org/10.1177/00222194050380040801

Dowker, A. (2013). *Interventions for children with mathematical difficulties*. Paper EARLI conference August 27th Munchen.

Dowker, A. D., & Sigley, G. (2010). Targeted interventions for children with mathematical difficulties. *British Journal of Educational Psychology*, Monograph Series *II* ,7, 65–81. http://dx.doi.org/10.1348/97818543370009X12583699332492

Dunn, S., Matthews, L., & Dowrick, N. (2010). Numbers count: developing a national approach to intervention. In I. Thompson (ed.). *Issues in Teaching Numeracy in Primary Schools* (pp. 224-234). Maidenhead: Open University Press.

Flouri, E. (2006). Parental interest in children's education, children's self-esteem and locus of control, and later educational attainment: Twenty-six year follow-up of the 1970 British birth cohort. *British Journal of Educational Psychology, 76(1),* 41-55. http://dx.doi.org/10.1348/000709905X52508

Fuchs, L.S. (2011). Mathematics intervention at the secondary prevention level of a multitier prevention system: Six key principles. Retrieved from: http://www.rtinetwork.org/essential/tieredinsstruction/tier2/mathintervention.

Fuchs, L.S., Powerll, S.R., Seethaler, P.M., Cirino, P.T., Fletcher, J.M., Fuchs, D., & Hamlett, C.L. (2010). The effects of strategic counting instruction, with and without deliberate practice, on number combination skills among students with mathematics difficulties. *Learning and Individual Differences, 20(2),* 89-100. http://dx.doi.org/10.1016/j.lindif.2009.09.003

Gallistel, C.R., & Gellman,R. (1992). Preverbal and verbal counting and computation. *Cognition, 44(1-2),* 43-74. http://dx.doi.org/10.1016/0010-0277(92)90050-R

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology, 47(6),* 1539-1552. http://dx.doi.org/10.1037/a0025510

Glauert, E. (2009). How young children understand electric circuits: prediction, explanation and exploration. International Journal of Science Education, 31(8), 1025-1047. http://dx.doi.org/10.1080/09500690802101950

Glauert, E., & Manches, A. (2013). *Creative little scientists: Enabling creativity through science and mathematics in preschool and first years of primary education. D2.2. Conceptual framework.* http://www.creative-little-scienstists.eu

Greenes, C., Ginzburg, H.P., & Galfanz, R. (2004). Big math for little kids. *Early Childhood Research Quarterly, 19(1),* 159-166. http://dx.doi.org/10.1016/j.ecresa.2004.01.010

Grégoire, J., Noël, M., & Van Nieuwenhoven (2004). TEDI-MATH. Antwerpen: Harcourt.

Griffin, S. (2004). Building number sense with Number Worlds: A mathematics program for young children. *Early Childhood Research Quarterly, 19(1),* 173–180. http://dx.doi.org/10.1016/j.ecresq.2004.01.012

Halberda, J., Mazzocco, M. M. M., & Feigenson, L. (2008). Individual differences in non-verbal number acuity correlate with math achievement. *Nature, 455(7213),* 665-662. http://dx.doi.org/10.1038/nature07246

Haseler, M. (2008). Making intervention in numeracy more effective in schools. In A. Dowker (Ed.), *Mathematical difficulties: Psychology and education* (pp. 225-241). London, UK: Elsevier.

Hollingshead, A. B. (1975). Four factor index of social status. Yale University, New Haven, CT.

Jordan, N.C., Kaplan, D. Ramineni, C., & Locuniak, M.N. (2009). Early matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology, 45(3), 850-867.* http://dx.doi.org/10.1037/a0014939

Jordan, N.C., Glutting, J., Dyson, N., Hassinger-Das, B., & Irwin, C. (2012). Building Kindergartner’s Number Sense: A Randomized Controlled Studylazer, M., *Journal of Educational Psychology, 104(3),* 647-660. http://dx.doi.org/10.1037/a0029018

Kaufmann, L., Delazere, M., Pohle, R., Semenza, C., & Dowker, A; (2005). Effects of a specific numeracy educational program in kindergarten children: A pilot study. *Educational Research & Evaluation, 11(5),* 405-431. http://dx.doi.org/10.1080/13803610500110497

Kaufmann, L. Handl, P., & Thöni , B. (2003).Evaluation of a numeracy intervention program focusing on basic numerical knowledge and conceptual knowledge: A pilot study. *Journal of learning disabilities* , *36(6)*, 564-573. http://dx.doi.org/10.1177/00222194030360060701

Klein, A., & Starkey, P. (2008). Fostering preschool children's mathematical knowledge: Findings from the Berkeley Math Readiness Project. In D.H Clements, J. Sarama, & A.M. DiBiase (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education* (pp. 343-360). Mahwah, NJ: Erlbaum.

Kolkman, M.E., Kroesbergen, E.H., & Leseman, P.P.M. (2013). Early numerical development and the role of non-symbolic and symbolic skills. *Learning and Instruction*, *23(2013)*, 95-103. http://dx.doi.org/10.1016/j.learninstruc.2012.12.001

Krajewski, K., & Schneider, W. (2009). Exploring the impact of phonological awareness, visual-spatial working memory, and preschool quantity-number competencies on mathematics achievement in elementary school: findings from a 3-year longitudinal study. *Journal of Experimental Child Psychology, 103(4)*, 516-31. http://dx.doi.org/10.1016/j.jecp.2009.03.009

Kroesbergen, E.J., & Van Luit, J.E.H. (2003) Mathematics interventions for children with special educational needs. A meta- analysis. *Remedial and Special Education*, *24(2)*, 97-114. http://dx.doi.org/10.1177/07419325030240020501

Landerl, K., Bevan, A., & Butterworth, B. (2004) Developmental Dyscalculia and basic numeral capacities: a study of 8-9-year-old-students. *Cognition, 93(2004)*, 99-125. http://dx.doi.org/10.1016/j.cognition.2003.11.004

Lee, S.W.-Y., Tsai, C.-C., Wu, Y.-T., Tsai, M.-J., Liu, T.-C., Hwang, F.-K. et al. (2011). Internet-based science learning: a review of journal publications. *International Journal of Science Education, 33* (14), 1893-1925. http://dx.doi.org/10.1080/09500693.2010.536998

LeFevre, J. - A., Smith-Chant, B. L., Fast, L., Skwarchuk, S. -L., Sargala, E., Arnup, J. S., . . . Kamawar, D. (2006). What counts as knowing? The development of conceptual and procedural knowledge of counting from kindergarten through Grade 2. *Journal of Experimental Child Psychology, 93(4)*, 285−303. http://dx.doi.org/10.1016/j.jecp.2005.11.002.

Lyytinen, H., Ronimus, M., Alanko, A., Poikkeus, A., & Taanila, M. (2007). Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psycholgy, 59(2)*, 109-126. http://dx.doi.org/10.1027/1901-2276.59.2.109

Mazzocco, M. M. M., Devlin, K. T., & McKenny, S. J. (2008). Is it a fact?Timed arithmetic performance of children with mathematics learning disabilities (MLD) varies as a function of how MLD is defined. *Developmental*

Neuropsychology, 33(3), 318-344. http://dx.doi.org/10.1080/87565640801982403

Missall, K., Mercer, S., Martínez, R. S., & Casebeer, D. (2012). Concurrent and longitudinal patterns and trends in performance on early numeracy curriculum-based measures in kindergarten through third grade. *Assessment for Effective Intervention, 37(2)*, 95-106. http://dx.doi.org/10.1177/1534508411430322

Morgan, P.I., Farkas, G., & Wu , Q (2009). Five-year growth trajectories of kindergarten children with learning difficulties in mathematics. Journal of Learning Disabilities, 42(4), 306-321. http://dx.doi.org/10.1177/0022219408331037.

Mussolin, C., Mejias, S., & Noël, M.P. (2010) Symbolic and nonsymbolic number comparison in children with and without dyscalculia. Cognition, 115 (1), 10-25. http://dx.doi.org/10.1016/j.cognition.2009.10.006

National Research Council (2009). *Mathematic learning in early childhood: Paths toward excellence and equity.* Washington, DC: National Academies Press.

Niederhauser, D.S., & Stoddart, T. (2001). Teachers' instructional perspectives and use of educational software. *Teaching and Teacher Education, 17(1),* 15-31. http://dx.doi.org/10.1016/S0742-051X(00)00036-6

Opel, A., Zaman, S.S., Khanom, F., & Aboud, F.E. (2012). Evaluation of a mathematics program for preprimary children in rural Bangladesh. *International Journal of Educational Development, 32(1),* 104-110. http://dx.doi.org/10.1016/j.ijedudev.2011.01.013

Ortega-Tudela, J.M., & Gomez-Arizat, C.J. (2006). Computer-assisted teaching and mathematical learning in Down syndrome children. *Journal of Computer Assisted Learning, 22(4),* 298-307. http://dx.doi.org/10.1111/j.1365-2729.2006.00179.x

Parsons, S. & Bynner, J.(2005). *Does Numeracy Matter More?* London: NRDC.

Piazza, M., Facoetti, A.,, Trussardi, A.N., Berteletti, I., Conte, S., Lucangeli, D., Dehaene, S., & Zorzi M (2010). Developmental trajectory on number acuity reveals a severe impairment in developmental dyscalculia. *Cognition, 116(1),* 33–41. http://dx.doi.org/10.1016/j.cognition.2010.03.012

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development, 79(2),* 375-394. http://dx.doi.org/10.1111/j.1467-8624.2007.01131.x

Ramani, G. B., & Siegler, R. S. (2011). Reducing the gap in numerical knowledge between low- and middle-income preschoolers. *Journal of Applied Developmental Psychology, 32(3),* 146-159. http://dx.doi.org/10.1016/j.appdev.2011.02.005

Ramey, C. T., & Ramey, S. L. (1998) Early intervention and early experience. *American Psychologist, 53(2)*, 109-120. http://dx.doi.org/10.1037/0003-066x.53.2.109

Randel, J., Morris, B., Wetzel, C.D., & Whitehall, B. (1992). The effectiveness of games for educational purposes: A review of recent research. *Simulation & Gaming, 23(3),* 261-276. http://dx.doi.org/10.1177/1046878192233001

Räsänen, P., Salminen, J., Wilson, A.J., Aunio, P., & Dehaene, S. (2009). Computer-assisted intervention for children with low numeracy skills. *Cognitive Development, 24(4)*, 450-472. http://dx.doi.org/10.1016/j.cogdev.2009.09.003.

Regtvoort, A., Zijtstra, H., & van der Leij, A. (2013). The Effectiveness of a 2-year Supplementary Tutar-assisted Computerized Intervention on the Reading Development of Beginning Readers at Risk for Reading Difficulties: A Randomize Controlled Trial. Dyslexia, 19(4), 256-280. http://dx.doi.org/10.1002/dys.1465

Reigosa-Crespo, V., Valdes-Sosa, M., Butterworth, B., Estävez, N., Rodräguez, M., Santos, E., Torres, P., Suérez, R., & Lage, A. (2012). Basic numerical capacities and prevalence of developmental dyscalculia: the Havana survey. *Developmental Psychology, 48(1)*, 123-135. http://dx.doi.org/10.1037/a0025356

Reusser, K. (2000). Co-constructivism in educational theory and practice. In N.J. Smelser, P., Baltes , & F.E. Weinert (eds.). International Encyclopedia of the Social and Behavioral Sciences . Oxford:Pergamon/Elsevier Science.

Riccomini, P. J., & Smith, G. W. (2011). Introduction of response to intervention in mathematics. In R. Gersten & R. Newman-Gonchar (Eds.) Response to intervention in mathematics. Baltimore, MD: Brookes Publishing

Rolando, L.G.R., Salvador, D.F., Luz, M.R.M. (2013). The use of internet tools for teaching and learning by in-service biology technology: A survey in Brazil. *Teacher and Teacher Education, 34(2013),* 46-55. http://dx.doi.org/10.1016/j.tate.2013.03.007

Rubie-Davies, C. M., & Peterson, E. (2010). Teacher expectations and beliefs: Their influence on the socioemotional environment of the classroom. In Rubie-Davies, C. M. (Ed.) *Educational Psychology: Concepts, research and challenges* (pp. 134-149). Routledge: London.

Salmani-Nodoushan, M.A. (2009). The Shaffer-Gee perspective: Can epistemic games serve education? *Teacher and Teacher Education, 25(6)*, 897-901

Shaffer, D.W., & Gee, J.P. (2005). *Before every child is left behind: How epistemic games can solve the coming crisis in education.* Madison, WI: Winsconsin Center for Educational Research.

Shalev, R. S., & Gross-Tsur, V. (2001). Developmental dyscalculia. *Pediatric Neurology, 24(5),* 337-342. http://dx.doi.org/10.1016/S0887-8994(00)00258-7

Siegler, R.S., & Booth, J.L. (2004) Development of numerical estimation in young children. *Child Development,* 75(2), 428-444. http://dx.doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R.S., & Opfer, J.E. (2003) The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science, 14(3)*, 237-243. http://dx.doi.org/10.1111/1467-9280.02438

Siegler, R.S., & Ramani, G.B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science, 11(5)*, 655-661. http://dx.doi.org/10.1111/j.1467-7687.2008.00714.x

Siegler, R.S., & Ramani, G.B. (2009). Playing linear number board games – but not circular ones – improves low-income preschoolers' numerical understanding. Journal of Educational Psychology, 101(3), 545-560. http://dx.doi.org/10.1037/a0014239

Slavin, R.E., Lake, C., & Groff, C., (2009) Effective Programs in Middle and High School Mathematics: A Best-Evidence Synthesis. Review of Educational Research, 79 (2), 839-911. http://dx.doi.org/10.3102/0034654308330968

Slusser, E.B., Santiago, R.T., & Barth, H.C. (2013). Developmental change in numerical estimation. Journal of experimental psychology, 142(1), 193-208. http://dx.doi.org/10.1037/a0028560.

Stock, P., Desoete A., & Roeyers H. (2010). Detecting children with arithmetic Disabilities From Kindergarten : Evidence From a 3-year longitudinal Study on the Role of Preparatory Arithmetic Abilities . Journal of learning Disabilities, 43 (3), 250-268. http://dx.doi.org/10.1177/0022219409345011

Sylvia, K. (2009). *Early childhood matters: Evidence from the effective preschool and primary education project* London: Taylor and Francis.

Templeton, T.N., Neel, R.S., & Blood, E., 2008; Meta-Analysis of Math Interventions for Students With Emotional and Behavioral Disorders *Journal of Emotional and Behavioral Disorders*,16 (4), 226-239. http://dx.doi.org/10.1177/1063426608321691

Toll, S.W.M., & Van Luit, J.E.H. (2013). Accelerating the early numeracy development of kindergartners with limited working memory skills through remedial education. *Research in Developmental Disabilities, 34(2),* 745-755. http://dx.doi.org/10.1016/j.ridd.2012.09.003

Toll, S.W.M. (2013). A journey towards mathematics. Effects of remedial education on early numeracy. PhD: University of Utrecht. The Netherlands.

Torgerson, C.J., A. Wiggins, D.J. Torgerson, H. Ainsworth, P. Barmby, C. Hewitt, K. Jones, V. Hendry, M. Askew, M. Bland, R. Coe, S. Higgins, J. Hodgen, C. Hulme, & Tymms, P. (2011). Every Child Counts: The Independent Evaluation. London: Department for Education.

UNESCO. (2008). ICT competency standards for teachers. Policy framework. UNESCO.

Vanderheyden, A.M., Broussard, C., Snyder P., George J., & Lafleur, S.M. Measurement of Kindergartners'Understanding of Early Mathematical Concepts. *School Psychology Review, 40(2),* 296-306 ISSN 0279-6015

Van de Rijt, B.A.M, & Van Luit, J.E.H. (1998). Effectiveness of the additional early mathematics program for teaching children early mathematics. *Instructional Science, 26(5)*, 337-358. http://dx.doi.org/10.1023/A:1003180411209

Van Luit, J.E.H., & Schopman, A.M. (2000). Improving early numeracy of young children with special educational needs. *Remedial and Special Education, 21(1)*, 27-40. http://dx.doi.org/10.1177/074193250002100105

Van Luit, J.E.H., & Toll, S.W.M. (2013). *Op weg naar rekenen.* [The road to mathematics]. Doetinchem, The Netherlands: Graviant.

Von Aster M.G., & Shalev R.S. (2007). Number development and developmental Dyscalculia. Developmental Medicine & Child Neurology, 49(11), 868-873. http://dx.doi.org/10.1111/j.1469-8749.2007.00868.x

Wechsler, D., Kort, W., Schittekatte, M., Bosmans, M., Compaan, E.L., Dekker, P.H., & Verhaeghe, P. (2002). Wechsler Intelligence Scale for Children-III-Nl. Amsterdam, The Netherlands: Harcourt.

Wilson, A.J., & Räsänen, P. (2008). Effective interventions for numercacy difficulties/disorders. Encyclopedia of Language and Literacy Development (pp1-11). London, ON : Canadian Language and Literacy research Network.Retrieved from http:// www.literacyencyclopedia.ca/pdfs/topic.php?topId=259

Wilson, A. J., Revkin, S.K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of "The Number Race", an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions, 2* (20) , http://dx.doi.org/10.1186/1744-9081-2-20.

Witzel, B.S., Mink, D.V., & Riccomini, P.J. (2011). Using visual representations to instruct and intervene with secondary mathematics. In R. Gersten & R. Newman-Gonchar (Eds.), *Understanding RTI in Mathematics. Proven methods and applications* (pp 151-167). Baltimore, ML : Brookes.

Whyte, J.C., & Bull, R. (2008). Number games, magnitude representation, and basic number skills in preschoolers. *Developmental Psychology, 44(2)*, 588-596. http://dx.doi.org/10.1037/0012-1649.44.2.588

Xu, F., & Arriaga,R.I. (2007) Number discrimination in 10-month-old infants. British Journal of Developmental Psychology, 25(1), 103-108. http://dx.doi.org/10.1348/0261510005x90704

III.
DISCUSSION AND DUTCH SUMMARY

9

Chapter 6

GENERAL DISCUSSION

This final chapter encloses a summary and discussion of the main findings. Additionally, limitations of the present studies and suggestions for future research are outlined. In conclusion, practical implications and recommendations are described.

1. Recapitulation of research goals, methods and main findings

1.1. RESEARCH GOALS

The **main goal** of this doctoral research was to gain an insight into the relationship between language and arithmetic learning in primary school children, on a behavioural level, using various different studies. Until now, this relationship has not been investigated in detail in addition to other arithmetic proficiency predictors. Plus we were also interested in the evolution of the number line. Finally, as the *M-decreet* (Measures for pupils with specific educational needs; Flemish Ministry of Education and Training, 2014) wants to promote the increasing inclusion of all children (including low performing children) in mainstream educational settings, we wanted to know the effect of two computerised interventions (serious games) in kindergarten on children in general and, more specifically, on low-performing children. The 'low performers' in this doctoral research were children with early arithmetic abilities in kindergarten at a level below the 25th percentile. As early arithmetic abilities are strong predictors of later school achievements, perhaps if markers for arithmetic development can be recognised, it may be possible to prevent children from falling further behind.

Literature research revealed a large body of evidence for the central influence of **counting** on the development of adequate arithmetic skills.
In addition, although a great deal of research looked into counting as a unitary ability, Dowker (2005) suggested that counting knowledge consists of procedural and conceptual aspects.
It has been suggested that children's basic conceptual understanding of how to count objects, as well as their knowledge of the order of numbers, play an important role in arithmetic performance because they promote the automatic use of arithmetic-related information, allowing attentional resources to be devoted to more complex arithmetic problem solving (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004).
We therefore wanted to look at the influence of language, in addition to counting, as a predictor for arithmetic proficiency in this doctoral research.

A literature review also revealed that **estimation** is needed to develop adequate arithmetic skills too.

According to the Triple Code model, there are three types of estimation tasks: two are symbolic: a visual Arabic number form (e.g., ‘5’) and a verbal word frame with number-words (e.g., ‘five’), and one is non-symbolic: the analogue magnitude representation (e.g., five dots). The number of studies ongoing in the ‘estimation’ area is therefore growing rapidly. However, the studies are often cross-sectional in nature, making predictions of individual differences in arithmetic difficult. In addition, the focus lies on non-symbolic estimation tasks in most studies, sometimes in combination with the symbolic tasks with Arabic numbers. Surprisingly few studies have been conducted to explore the relationship between estimations on a number line estimation task, with a 0-100 interval in three formats (Arabic digits, dots and number), adding language as a predictor and focusing on timed and untimed arithmetic learning.

We therefore aimed to study children’s estimation skills with a longitudinal design, resulting in a gain in precision of number line judgments on a 0-100 interval (resulting in a lower Percentage of Absolute Errors, PAE). The developmental transition from a logarithmic representation of numbers to a linear one from preschool to primary school was also investigated in these children. In addition, we investigated the relationship between language and estimation, focusing on timed and untimed arithmetic learning (chapter 4).

The principal aim of this dissertation was to investigate the role of **language** as a preparatory arithmetic ability in a large group of children with a broad range of abilities. Literature research revealed there is evidence of a significant relationship between language and arithmetic, but that it remains unclear to what extent language has an additive value to other established predictors such as counting and estimation as preschool predictors.

We intentionally opted for studies on a behavioural level (see model by Morton and Frith (1995) in chapter 1), as there is no consensus regarding the cognitive or biological deficit(s) involved in children with a typical and atypical development or on an explanatory level.

The research goal was therefore to investigate whether language had an additive value in relation to other established predictors, such as counting and estimation, in the prediction of early arithmetic skills in kindergarten and (untimed) calculation proficiency in grade 1 (chapter 2). Plus we also explored if (timed) fact retrieval skills in grade 1 and 2 also depend on preschool language (chapter 3).

Finally, we studied the effects of a short and intensive **intervention** of playing educational (counting and comparison) games in kindergarten on the overall arithmetic learning proficiency and on the estimation skills in grade 1.

The final research goal was therefore to investigate whether an adaptive computerised counting or comparison intervention in kindergarten could enhance the arithmetic skills in grade 1. A study was also conducted to see if intensive gaming in kindergarten could lead to an improvement in number line estimation accuracy (chapter 5).

In conclusion, given the high social and individual costs associated with poorly developed arithmetic skills (Geary, 2011) and the introduction of the *M-decreet* (Measures for pupils with specific educational needs; Flemish Ministry of Education and Training, 2014) promoting inclusion of all children (also low performing children) in mainstream educational settings, it is essential to gain an insight into the early arithmetic development. We therefore empirically investigated the value of language as one of the potential predictors, in addition to other known predictors for arithmetic in grade 1 (chapter 2) and grade 2 (chapter 3). Secondly, the evolution of number line estimations was studied from kindergarten up to grade 2 in chapter 4. Finally, we investigated whether we could enhance arithmetic proficiency with a preventive computerised intervention. We therefore empirically evaluated the effect of a short computerised comparing and counting intervention in chapter 6.

1.2 MATERIALS

1.2.1. LANGUAGE (TESTED IN KINDERGARTEN)

To get a picture of the language skills, 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) in kindergarten.

The CELF-$_4$Nl results in a core language score or a measure of general language ability that quantifies children's overall language performance. In addition, the CELF-IV results in a receptive language index, an expressive language index, a language content index and a language structure index.

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 structures.

The psychometric value of the CELF-$_4$Nl in this study was good with Cornbach's alpha = .95. Cronbach's alpha of the core language score was .93. Cronbach's alpha of the receptive score was .946. Cronbach's alpha of the expressive score was .93. The Cronbach's alpha for the content index and the structure index were .94 and .93 respectively.

1.2.2. EARLY ARITHMETIC (TESTED IN KINDERGARTEN)

In order to obtain an overview of the kindergarten abilities of children, subtests of the Test for the Diagnosis of Mathematical Competencies (TEDI-MATH; Grégoire, Noël, & Van Nieuwenhoven, 2004), a Belgian individual Assessment Battery, were completed.

The psychometric value of the battery was tested on a sample of 550 Dutch-speaking Belgian children and the TEDI-MATH has proven to be a conceptually accurate and clinically relevant instrument and its predictive value has been demonstrated in several studies. The values for Cronbach's Alpha ranged from .70 to .97.

Early arithmetic skills were assessed (in kindergarten) using a subtest of the TEDI-MATH (Grégoire et al., 2004). A series of six visually supported addition and subtraction exercises were presented to all children. The maximum total raw score was 6. Cronbach's Alpha of this subscale was .85.

The **procedural counting knowledge** was assessed (in kindergarten) using accuracy in counting rows and counting forward to an upper bound and/or from a lower bound. The task consisted of eight items and had a maximum raw score of 8.

The **conceptual counting knowledge** was assessed (in kindergarten) by judging the validity of counting procedures, based on five basic counting principles. In order to investigate these principles, children had to judge the count of both linear and nonlinear patterns of objects, and were asked some questions about the number of objects they counted (e.g. "How many objects are there in total?"). The maximum total raw score for this subtest was 13.

1.2.3 ARITHMETIC (TESTED IN GRADE 1 AND 2)

In order to obtain a complete overview of the arithmetic abilities of children, a timed and an untimed arithmetic test were used. These tests were used in chapters 2, 3, 4 and 5. There are several arguments for these two tests. First of all, there is neuroimaging evidence for the involvement of the prefrontal cortex in maintaining temporal order information (important for calculation), and the gyrus angularis has been associated with arithmetic fact retrieval. There is thus a strong neural basis for the differentiation between timed and untimed arithmetic tasks. Second, there is behavioural evidence of subtypes in children with mathematical learning disorders. The procedural subtype is characterised by a developmental delay in the acquisition of arithmetic (calculation) procedures and the semantic memory subtype encompasses developmental deficits in verbal memory and errors in the retrieval of number facts.

Fact retrieval or **timed arithmetic proficiency** was tested with the Arithmetic Number Facts Test (Tempo Test Rekenen, TTR; De Vos, 1992). The TTR is a numerical facility test (measuring timed arithmetic skills) consisting of five subtests with arithmetic number fact problems: addition, subtraction, multiplication, division and mixed exercises. Children have to solve as many items as possible in five minutes; they can work one minute on every column. The TTR is a standardised test frequently used in Flemish education as a measure of number fact.

Untimed calculation proficiency was tested with the Kortrijk Arithmetic Test Revision (Kortrijkse Rekentest Revisie, KRT-R; Baudonck et al., 2006) and with the CDR. The KRT-R is a standardised test of arithmetic achievement requiring children to solve mental arithmetic and number knowledge tasks (without strict time limit). The KRT-R and the CDR are frequently used in Flemish education as a measure of procedural, untimed arithmetic calculation skills.

Cronbach's alpha in grade 1 and grade 2 were .87 and .89 respectively for the KRT-R and .72 for the CDR.

1.2.4 ESTIMATION

A number line estimation task with a 0-100 interval was completed at 5 time points (from kindergarten till grade 2 – see chapter 4). The number line estimation task is based on the task by Booth and Siegler (2006) and Siegler and Booth (2004) for the corresponding age group.

The task included 3 exercise trials and 30 test trials. The left end anchor was labelled 0 and the right 100; the number to be positioned appeared 2 cm above the centre of the line. Stimuli were presented in three different formats following the Triple Code model (on an iPad). In the visual Arabic format, stimuli were presented as Arabic numerals (e.g., anchors 0 and 100, target number 25); target numbers were not read out. In the auditory verbal format, stimuli were presented as spoken number words (e.g., anchors zero and hundred, target number 18), and in the analogue magnitude format, stimuli were presented as dot patterns (e.g., anchors of zero dots and hundred dots, target number three dots). The dot patterns consisted of black dots in a white disc. Dot patterns were controlled for perceptual variables using the procedure by Dehaene, Izard, and Piazza (2005), meaning that in half the trials the dot size was held constant, while in the other half, the size of the total occupied area of the dots was held constant. When composing the task, both the format of the target numbers as well as the presented numerosities was chosen randomly. However, once determined, this order was the same for each participant. Ten target numbers were selected: 2, 3, 4, 6, 18, 25, 42, 67, 71 and 86 (corresponding to sets A end B in Siegler and Opfer, 2003). Children were asked to put a single mark on the line to indicate the location of the number. Although the instructions could be rephrased if needed, no feedback was given to participants regarding the accuracy of their marks. The PAE was calculated per child as a measure of the children's estimation accuracy, following the formula of Siegler and Booth (2004).

In order to investigate the underlying representation of the estimates, their procedure was used. Booth and Siegler (2006) revealed developmental changes in number line estimation tasks related to individual differences in arithmetic achievement. Therefore, on a group level, regression analyses of the group medians were used to compute both linear and logarithmic fits. The difference between the two fits was tested with a paired samples t-test, calculating the absolute difference between the median estimate for each number and the predicted values based on the linear and logarithmic models respectively. On an individual level, following the procedure of Bertelli, Lucangeli, Piazza, Dehaene, & Zorzi (2010), each child was attributed the best fitting significant model between linear and logarithmic. A child was classified as not having a valid representation when both coefficients failed to reach significance.

1. 3. MAIN FINDINGS

1.3.1. LANGUAGE

Kindergarten language in the prediction of (timed and untimed) arithmetic in kindergarten, grade 1 and 2 was examined in Chapters 2 and 3.

Chapter 2 investigated whether kindergarten language explained some of the variance in **(untimed) arithmetic skills in grade 1**, when checking for other known predictors (such as counting knowledge and early arithmetic skills in kindergarten). Our data (n = 63) revealed that language explained 21.6% of the variance in arithmetic skills in kindergarten. When we checked for kindergarten arithmetic skills (tested with the TEDI-MATH), language still predicted untimed grade 1 arithmetic proficiency (tested with KRT-R) with an explained variance of 4.9%.

Chapter 3 differentiated between the predictions for **untimed and timed arithmetic skills in grades 1 and 2**. In addition, the different language indexes were compared and the results of more children were analysed. Our data (n = 132) confirmed the previous (chapter 2) prediction. Language had additional predictive power for untimed arithmetic calculation (tested with KRT-R) in grade 1. This was also the case in grade 2 and the prediction was significantly over and above the prediction of counting and estimation. However, language did not add to the prediction of untimed arithmetic (fact retrieval skills – tested with TTR) in grade 2.

1.3.2 NUMBERLINE ESTIMATION

Number line estimation was studied in typically developing children in Chapter 4. The estimation on a number line task in three formats (Arabic digits, dots and number) was studied in a sample of 132 children, followed from kindergarten up to grade 2 (Praet & Desoete, 2014b).

Results revealed variability in estimation accuracy and errors declined with age and instruction in all children.
In addition, intelligence (assessed in kindergarten) explained part of the variability in intercepts and slopes, whereas language (also assessed in kindergarten) explained variation when children enter the school system (in kindergarten), but not in the evolution of growth curves and, in particular, untimed math achievement could be predicted by number line estimation.

1.3.3. MODIFIABILITY OF ARITHMETIC SKILLS

We examined whether computer games in kindergarten can enhance the arithmetic learning proficiency in grade 1 in Chapter 5. We therefore used an intervention study in kindergarten. We empirically evaluated the effect of a short computerised comparison and counting intervention.

Results revealed that the kindergartners' arithmetic skills increased with training effects which were persistent in grade 1. In particular, computer games supporting the development of counting skills enhanced the overall arithmetic learning proficiency in grade 1.

In addition, the results of kindergarteners with ‘additional educational needs’ at-risk (*n* = 40) for mathematics difficulties (because of their <pc 25 scores in kindergarten on the TEDI-MATH) were compared to the results of a peer group (*n* = 92) with at least average skills. 14 at-risk children and 30 not-at-risk children participated with the counting condition and 10 at-risk children and 29 not-at-risk children participated with the number comparison skills condition. The business-as-usual group included 16 at-risk children and 33 not-at-risk children. The findings indicated that a short and intensive intervention of playing educational games filled the gap between at-risk children and peers without additional educational needs. Kindergartners’ mathematic skills increased with training. These effects were persistent in grade 1.

2. COVERING CONCLUSIONS AND DISCUSSION

The conclusions from the studies conducted in this doctoral study can be integrated with previous literature and summarised in 4 pillars: language, arithmetic, estimation and intervention.

2.1. CONCLUSIONS REGARDING LANGUAGE

A literature review revealed that whether or not language and, for example, the knowledge of number words, helps preschool children to solve mathematical problems remained a point of discussion as Levine, Jordan and Huttenlocher (1992) and Canobi and Bethune (2008) demonstrated that preschool children were better problem solvers in the absence of number words. Canobi and Bethune (2008) and Patel and Canobi (2010) also demonstrated the accuracy of solving problems was the same between verbal and non-verbal tasks. Nevertheless, Cowan and Renton (1996) indicated that with a commutative (e.g., 2 + 4=4+2) judging task, number words facilitate mathematical reasoning. A larger nominal vocabulary was also found to be helpful when learning number words (Negen & Sarnecka, 2012). In addition, some studies (Barner, Chow, &

Yang, 2009; Negen & Sarnecka, 2012) revealed that general language development measures also predict number-word knowledge, although other studies (e.g., Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003) did not find such a link.
In summary, available research regarding the relationship between arithmetic and language was rather inconclusive and the additional predictive power of language for procedural calculation and fact retrieval over and above counting and number estimation variables as predictors for arithmetic has empirically been poorly documented.

The aim of this doctoral research was to extend the available studies by providing information about the relationship at the end of preschool (or before the start of formal schooling) and at the beginning of grade 1 (or at the start of formal schooling). We also investigated whether or not language is important for all arithmetic tasks (such as timed fact retrieval and untimed calculation proficiency). We therefore examined language skills in Chapters 2, 3 and 4. We investigated whether better developed language skills were related to higher arithmetic scores (in addition to motor skills, handwriting quality and handwriting speed).

The core language index added one-fifth to the prediction of early arithmetic skills in kindergarten (n = 63) in a **first study** (in chapter 2). When deconstructing the language component as arithmetic predictors, expressive language explained approximately one fourth of the variance in arithmetic skills among kindergartners when checking for counting knowledge. The prediction was significant in grade 1 (explained variance of 35.9 %), when taking the expressive language results into account. The stepwise regression revealed that productive language added approximately five percent to the prediction when checking for kindergarten arithmetic (Praet, Titeca, Ceulemans, & Desoete, 2013).

However, when analysing the prediction of language on the total sample (n = 132), the core language index represented 6.8% of the variance in grade 1 untimed arithmetic calculation skills. In **grade 2**, the core language index revealed 7.5% of additional explained variance, indicating an additional power of language for calculation accuracy in grade 2, over and above number estimation skills assessed in preschool. In conclusion, the core language index in kindergartners predicts a small (but unique and additional) amount of variance in untimed arithmetic skills in grade 1 and grade 2, over and above other known predictors (see 2.5. for more details).

The previous results were confirmed in a larger group of children (including the children from the first study and some additional children) in the **next study** (chapter 3). There was an additional predictive power of language (core index) for early arithmetic over and above counting and estimation, without language mediating the counting and estimation performances in preschool. All three tests (language, procedural counting knowledge and estimation) therefore seemed indicative of predicting arithmetic proficiency in kindergarten.
In grade 1 there was an additional predictive power of language over and above number estimation (about one tenth of the explained variance), without language mediating the prediction of number line estimation on untimed arithmetic skills in grade 1.
In grade 2 language had 6.5% additional explained variance for untimed arithmetic (calculation accuracy) over and above number estimation skills assessed in preschool. There was nearly no (0.5%) unique additional amount of variance explained by language, over and above procedural counting knowledge assessed in preschool, in relation to fact retrieval (speed) data. In conclusion, language does not replace the traditional tests (counting, estimation), but has some additional, explained variance for untimed arithmetic (but not for fact retrieval).

A latent growth curve model was used to study the changes in relationships between number line estimation, language and intelligence over time in a **third study** (chapter 4).
Our findings revealed that language influenced the starting point (in kindergarten), but not the development or evolution of the number line estimation accuracy (in grades 1 and 2).

Three conditions were compared in the fourth study (chapter 5). Serious games were found capable of enhancing children’s arithmetic skills.

When looking at the language skills of the three groups, no significant differences were found in relation to the core language index scores in kindergarten (F (2, 128) = 0.08; p = .919).

In summary, the studies (chapters 2, 3 and 4) revealed a relationship between arithmetic and language. Language had an additional predictive power for procedural calculation, but not for fact retrieval, over and above counting and estimation. Finally, our findings suggest that language in particular explains some **variation** in kindergarten, but not in evolution.

2.2. CONCLUSION REGARDING EARLY ARITHMETIC SKILLS

Arithmetic is inherently present in everyday life; we are confronted with it every single day, for example: paying in a shop, baking a cake or travelling by train...

A literature review revealed that individual differences in early numeracy and in foundations of arithmetic skills have been receiving growing attention in the past decade. However, up until now, research regarding these differences has mainly focused on the role of counting, without taking other predictors into account.

This doctoral study has specifically focused on typically developing children (chapters 2, 3, 4 and 5), in order to extend the available studies by providing information regarding the development of arithmetic in these children.

The **first study** (in chapter 2) revealed an explained variance for early arithmetic skills (assessed with the TEDI-MATH) in kindergarten of 60.8% with number naming (explained variance of 29.6%) and procedural counting knowledge (adding 8% to the prediction) as predictors.

Procedural counting knowledge, number naming and kindergarten arithmetic explained 35.9% of the variance of untimed procedural calculation (KRT-R) in grade 1. The stepwise regression revealed that, principally, kindergarten arithmetic (TEDI-MATH) predicted 29.9% of the variance in grade 1 arithmetic skills (KRT-R). This data replicated previous research regarding the relationship between counting and arithmetic (Stock, Desoete, & Roeyers, 2009; 2010). The cross-sectional analysis revealed that both types of counting knowledge (procedural and conceptual knowledge) predicted early arithmetic skills in kindergarten. However, when language was added to the prediction, only a trend for procedural counting knowledge remained present.

These findings underlined the value of number naming in kindergarten. However, the kindergarten number naming skills were no longer significant predictors for grade 1 arithmetic, checking for kindergarten arithmetic and language. Plus number naming and number line estimation do not appear to represent the same construct, so they should not be combined into a composite score.

Untimed arithmetic was added and the data of more children (n = 132) were analysed in the **second study** (chapter 3).

This analysis confirmed the relationship between counting and arithmetic. Procedural and conceptual counting knowledge assessed in preschool were concurrently related to early arithmetic skills in preschool. In addition, arithmetic calculation accuracy in grade 2 could be predicted by procedural counting knowledge in preschool.

In conclusion, these findings underlined the value of procedural counting knowledge in preschool, supporting the hypothesis that good number representations could form solid foundations for arithmetic development.

In summary, the studies confirmed that procedural and conceptual counting knowledge has a strong value in the prediction of arithmetic proficiency (calculation) in grades 1 and 2.

2.3 CONCLUSIONS REGARDING ESTIMATION

Estimation is an important skill both in the classroom and everyday life and one task to tap this ability is the number line task (Siegler & Booth, 2004).

Different paradigms were used to test the estimation proficiency in children in chapter 2: the number line estimation task, the number comparison task and the number naming task.

The **number line estimation task** requires an estimation of Arabic numerals, number words or dot arrays in relation to their position on a line, referring to a reflection of the value of numbers.

Children have to judge on which side of the screen they saw most dots in the **number comparison task**. This task requires the ability to understand the numerical magnitude of the presented stimuli, as it involves a comparison with the second number or dot pattern.
Children had to say the number of black squares they saw on the monitor out loud in the **number naming task**. Children have to make an association or 'translation' between a nonverbal representation and a verbal label in this task, or in other words, produce a mapping of number words to preverbal magnitudes. Children are asked to map number words onto numerosities (without necessarily grasping the meaning of the numerosities).

A literature review, as an introduction to chapter 4, indicated that the gain in precision or accuracy of number line judgments on a 0-100 interval is characterised by a developmental transition from a logarithmic representation of numbers to a more formally appropriate linear one from preschool to primary school, suggesting a changing representation with increasing formal schooling (Siegler & Booth, 2004; Siegler & Opfer, 2003). The importance of this evolution is demonstrated in studies indicating that the linearity of judgements is positively correlated with arithmetic scores (Ashcraft & Moore, 2012; Siegler & Booth, 2004). Some studies also revealed that, compared to typically developing children, children with mathematical learning disorders are less accurate in their judgements and rely more on a natural logarithmic rather than a formally appropriate linear representation when dealing with this task (e.g. Geary, Hoard, Nugent, & Byrd-Craven, 2008).
The current doctoral research addressed the question of the predictive value of non-symbolic and symbolic (number word and Arabic number) number line comparisons (according to the Triple Code model) for arithmetic, using a longitudinal design (chapters 2, 3 and 4). In addition, an intervention paradigm was used to investigate whether it was possible to enhance arithmetic and to what extent this intervention was effective where changing young children's number line estimation accuracy is concerned (chapter 4). We expected less mapping errors on the 0-100 number line estimation task when children attained better arithmetic skills.

Our findings (chapters 2) revealed that, in the first study (n = 63), number naming and number line estimation in kindergarten were predictive for untimed procedural calculation performances in grade 1. The mapping between a verbal and non-symbolic component (number naming) was an essential predictor of arithmetic abilities in the first grade.

In addition, estimation (chapter 3) (assessed with number line estimation) in the total sample (n = 132) predicted calculation accuracy but not speed in grades 1 and 2.

We also empirically demonstrated age-related changes in number-line estimations in three formats (chapter 4). Results revealed variability in estimation accuracy and errors declining with age and instruction in all children. Arabic numerals had a more linear distribution than number words. Our findings also suggested that untimed math achievement could particularly be predicted by number line estimation accuracy.

In addition (chapter 5), we focused on the effects of adaptive computerised counting or comparison intervention in kindergartens. Two thirds of the kindergartners, including children with and without poor calculation skills, received a computerised intervention. Playing serious counting games in kindergarten improved number knowledge and mental arithmetic performances in grade 1. However, we demonstrated no gain in number line estimation accuracy (Praet & Desoete, 2014a).

In conclusion, the current doctoral research revealed the predictive value of estimation for untimed arithmetic (calculation). However, although number line training increased arithmetic in other studies (Kucian, Grond, Rotzer, Henzi, Schonmann, Plangger, . . . von Aster, 2011; Ramani & Siegler, 2008; Siegler & Ramani, 2008), our findings revealed that children can improve their arithmetic skills (through counting or comparison training) without becoming more accurate in estimation on the number line, questioning the relationship between arithmetic and estimation.

2.4 CONCLUSIONS REGARDING SERIOUS GAMES IN KINDERGARTEN

A literature review revealed that the importance and feasibility of pre-literacy interventions as a head-start is internationally recognised. However, there is less

consensus regarding pre-numeracy intervention in kindergarten. Additionally, although several purposeful instructions were revealed to be effective in the enhancement of early numeracy, most of them are very intensive and take about 6 to 9 months and sometimes even longer to be effective. It also remains unclear whether all children would benefit from such a less intensive computerised intervention.
The effects of educational ICT technology were studied using a pre-test/post-test test design in this doctoral research. It was investigated whether a short and intensive intervention of playing educational games could enhance arithmetic in grade 1 and if such an intervention could fill the gap between at-risk children and peers without additional educational needs (Praet & Desoete, 2013).

We explored the effect of non-intensive, individualised, but very short (8 sessions of 25 minutes), computerised interventions (using child-friendly computer games) in kindergarten (in **chapter 5**). Two CAI groups – a counting and number comparison condition **-** were used to explore if one is more effective than the other as a computerised instruction variant. In addition, the control group was active, to prevent the Hawthorne effect (positive effects due to extra attention in de CAI groups).
The findings demonstrated that digital technology presented new opportunities for learning and exploring early numerical concepts and sharpened the actual learning process in young children. Even non-intensive and computerised adaptive interventions in kindergarten could enhance early numeracy in young children with a delayed effect on arithmetic performances in grade 1. Waiting until grade 1 to intervene, when arithmetic difficulties become persistent, seems a waste of valuable (instruction) time. In addition, we investigated the potential of the CAI on kindergartners with below average performance levels (< pc 25) in early calculation measures (in kindergarten). We demonstrated the preventive value of gaming in kindergarten as a look-ahead approach in enhancing arithmetic proficiency.

In conclusion, this study revealed, in line with Dowker (2013) and Ramani and Siegler (2008; 2011), that early numeracy can be stimulated in kindergarten, even in low performers, with a sustained effect on arithmetic in grade 1. This is good news for low performers. Playing educational counting games (see also

Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006 and Räsänen Salminen, Wilson, Aunio, & Dehaene, 2009) might create a buffer against poor arithmetic outcomes. In line with Sylvia (2009), we found that young children's early educational experiences might have an impact on later outcomes in terms of educational achievement and, perhaps, also on attitudes towards mathematics. Teachers and teacher educators should understand the importance of a rich environment, with opportunities for children to explore and make sense of numerical experiences and know that they can accelerate early numeracy development in kindergartners with educational games. Dawson (2003) revealed that teachers tend to underestimate the capabilities of young children when it comes to mathematics and may not have the knowledge to focus on important mathematical experiences. Therefore, this study's finding that it is possible to use computer software in an entertaining game-like format to provide learning experiences with an effect on later arithmetic proficiency, is an important finding. The discovery of counting's key role reminds us that exposure to counting games seems particularly applicable in kindergarten.

2.5. ADDITIONAL ANALYSES AND DISCUSSION

Only the data for half of the children was available in chapter 2. Some additional analyses were conducted in relation to the total sample of children in this section. Table 1 shows the correlations between all measures (two arithmetic measures, overall language and each of its components (assessed at T1) and estimation assessed in kindergarten) in relation to the total sample (*n* = 132).

The correlation matrix revealed a significant relationship between early calculation skills in **kindergarten** and the core language index, but also with the receptive, expressive, content and structure index in kindergarten.

In addition, there was a significant correlation between children's skills in **grade 1** to solve simple calculations and their core language index, estimation, receptive language, expressive language, language content and language structure assessed in kindergarten at T2.

Table 1

	TM (T1)	1 KRT-R.	2lg.core index	3	4	5	6NL PAE	7Numb Comp	8Numb Nam.	9 L Recep	10 L Exp.	11 L Content
1.KRT-R (T2)	.409*	-	-	-	-	-	-	-	-	-	-	-
2.Lg.Core Ind.	.482*	**.458***	-	-	-	-	-	-	-	-	-	-
3.Log. Think.	.548*	.387*	.390*	-	-	-	-	-	-	-	-	-
4.Proc. Count.	.446*	.145	.231*	.477*	-	-	-	-	-	-	-	-
5.Conc.Count.	.482*	.222	.312*	.453*	.372*	-	-	-	-	-	-	-
6. NL PAE	-.473	-.335*	-.345*	-.384*	-.233*	-.368*	-	-	-	-	-	-
7.NumbComp	.322*	.164	.251*	.249*	.151	.254*	-.159	-	-	-	-	-
8.Numb nam.	.084*	.055	.008	.159	.104	.231*	-.094	.105	-	-	-	-
9.Recept.Lang	.487*	.439*	.726*	.367*	.222*	.245*	.383*	.231*	.013	-	-	-
10 Exp. Lang.	.551*	.534*	.873*	.412*	.245*	.297*	-.435*	.270*	-.063	.731*	-	-
11 Lg. content	.502*	.406*	.743*	.398*	.234*	.287*	-.400*	.232*	.059	.779*	.800*	-
12Lg.structure	.497*	.466*	.918*	.393*	.204	.250*	-.323*	.238*	.067	.746*	.888*	.721*

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

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)

Several stepwise regression analyses were also conducted, with variance in arithmetic skills as the outcome, in addition to studying the prediction of **language** for kindergarten, grade 1 and grade 2 arithmetic proficiency.

The first regression analysis was significant (F (2, 128) = 28.256, $p < .001$, R^2 = .306) for procedural counting knowledge ($p < .001$) and conceptual counting knowledge ($p < .001$) in **kindergarten**. The regression analysis was also significant (F (2, 125) = 24.972, $p < .001$, R^2 = .285) for number comparison (p = .001) and for number line estimation ($p < .001$). The next regression also revealed significant (F (6, 121) = 19.358, $p < .001$, R^2 = .490) results for procedural counting knowledge (p = .016), estimation (p = .004), language core index (p = .003) and logical thinking (p = .016).

Therefore, when checking for the other predictors at T1, estimation added 6.7% of explained variance to the prediction and the core language index explained 6.9% of the variance in arithmetic skills among kindergarten. All four predictors simultaneously explained 25.8% of the variance.

The regression analysis in **grade 1,** with all these variables simultaneously entered as predictors, was also significant (F (5, 119) = 10.723, p <.001, R^2 = .311), with only significant results for the language core index (p = .004). A stepwise regression revealed that kindergarten language core index predicted 6.8% of the variance in grade 1 arithmetic skills (F (5, 119) = 10.723, $p < .001$, R^2 = .311).

Whereas especially productive language predicted 4.6% of the variance in chapter 2 (with half of the children), here (n = 132) the core index predicted approximately the same amount of variance (6.8%) of the untimed calculation skills in grade 1, over and above the other predictors (such as procedural counting knowledge and estimation). There was no significant prediction for timed arithmetic proficiency.

In a similar way, the inclusion of the core language index revealed 7.5% additional explained variance in **grade 2**, indicating an additional power of language for calculation accuracy in grade 2, over and above number estimation skills assessed in preschool (F (4, 115) = 20.619; p <.001, R^2 = .418)

In conclusion, the core language index in kindergartners predicts a small (but unique and additional) amount of variance in untimed arithmetic skills in grade 1 and grade 2, over and above known predictors (such as counting knowledge and estimation).

Divergent measures for **estimation** were used in this doctoral research. Most researchers focus on the positioning, estimation or mapping of numerals on a **number line** (e.g. Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Siegler & Booth, 2004). However, Hannula, Räsänen, & Lehtinen, 2007 and Fischer, Gebhardt, and Hartnegg (2008) used **number naming** or enumeration tasks to assess young children's estimation skills. 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, in order to acquire an insight into young children's estimation skills.

Our data revealed that the paradigm choice mattered and how you test and analyse is what you get.

The results regarding different estimation paradigms (number line estimation, number comparison and number naming) were compared in kindergarten for half of the children in chapter 2. The correlations were computed in line with the total sample (n = 132) in Table 1. There was a significant correlation between early calculation in kindergarten and number comparison, even with Bonferroni corrections. In addition, there was a significant correlation between children in grade 1's ability to solve simple calculations and their estimation proficiency assessed at T2.

In addition, number comparison and number naming skills significantly predicted the arithmetic skills in kindergarten (T1 with the small sample of children) and number naming only predicted arithmetic skills at the end of kindergarten (T2) in study 1 (chapter 2). Number line estimation was no significant predictor in this small sample. However, in the total sample (n = 132), number line estimation predicted 6.7% of the variance of kindergarten arithmetic skills on top of the other predictors. Number line estimation was no longer a predictor in the stepwise regression regarding the variance in grade 1 arithmetic skills when language was added as predictor.

When looking at estimation versus language in more detail, it became obvious that there was no significant correlation between number naming and any of the language indexes in kindergarten, whereas number line estimation and number comparison significantly correlated with all language indexes. The significant correlations varied between .231 and .-435, so the explained variance was limited (varying between 5.34% and 18.92%).

3. Strengths and weaknesses and ideas for future research

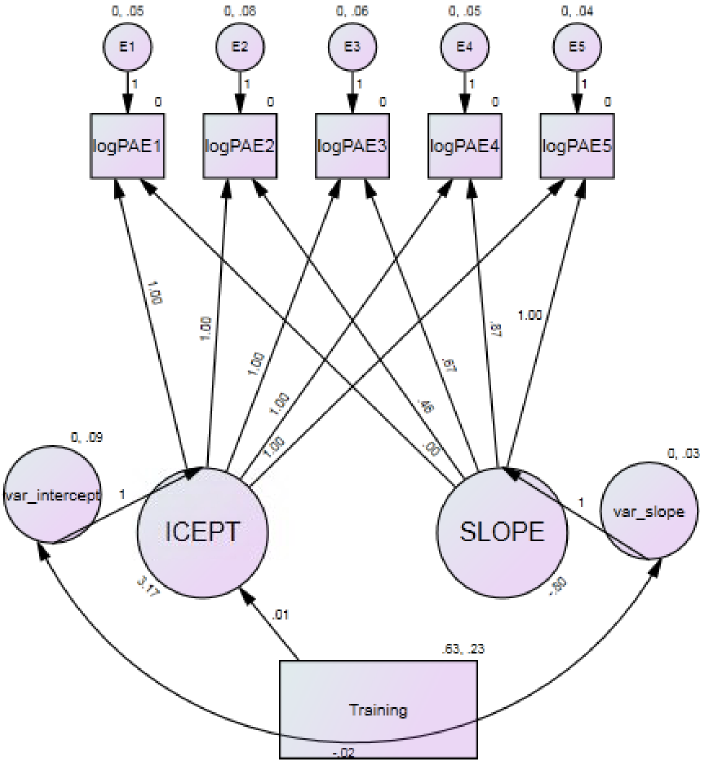
Several strengths, weaknesses and ideas for future research have been formulated in the current and previous chapters. In this section, we summarise the most important limitations of this research project and we outline some recommendations for future research.

A **limitation** of this doctoral research might be that due to the divergent (contradictory) models trying to describe or explain mechanisms underlying problems with arithmetic, we intentionally chose for research on **a behavioural level.** In doing so we used a longitudinal design, adding a novel component of arithmetic on top of the know predictors in the study of arithmetic proficiency. Moreover, we deliberately also studied number line estimation to add to the **explanatory level**.

Another limitation that has to be acknowledged is that 132 children were followed on the numberline task (chapter 4), with two thirds of them having an intervention in kindergarten (chapter 5). However was not a bias, because of two reasings.

Firstly, in a previous analysis we investigated the number line representation on 49 children (control group not getting an intervention). However when we compared this group (*n* = 49) with the total sample (*n* = 132) , the variable training had no significant effect (*p* =.907) on the Mean logPAE. Moreover, the geometric mean of the PAE score (or the mistakes children made on the number line estimation task) was (although not significant) even estimated to be 0.7% (95% CI (-10.1%, +12.9%) higher in the groups that got a training compared to the group that was not trained. So there was no bias by including the total sample in chapter 4, since no significant differences could be found between and the power of the analyses increased (see Figure 1).

Figure 1 : Latent Growth curve on estimation accuracy with training as covariate



Intercepts: (Group number 1 - Default model)

	Estimate	S.E.	C.R.	P	Label
ICEPT	3.170	.049	64.657	***	IMean
SLOPE	-.800	.040	-20.007	***	SMean

Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
ICEPT	<---	Training	.007	.057	.117	.907	

Secondly, Heim, Amunts, Drai, Eickhoff, Hautvast, and Grodzinksy, (2012) revealed that in apes there are two pariental regios: a place dealing with comparision and a place dealing with estimation. fMRI in humans also confirmed that these skills have to be differentiated from each other based on different frontoparietal bihemisferical localisation.
To conclude, according to us there was no bias by presenting the PAE and representation on the numberline on the total sample (*n* = 132) in chapter 4. However additional studies on a large sample of children seem indicated to corfime these findings, without some of the children getting a training during the longitudinal study.

In addition as mentioned above our data revealed that the choise of the paradigm mattered and how you test and analyse is what you get. In this doctoral study all children were assessed at the five measuring points with all three estimation paradigms (number naming, number comparison and number line estimation). However only in chapter 2 the data from the three paradigms were used. In other studies (chapter 3, 4 and 5) only the results of the number line estimation paradigms were analysed. The rest of the data will be available for future studies (but was beyond the scope of this doctoral study).

Another limitation is that we have to admit that arithmetic performance tasks are likely to involve a combination of cognitive and motivational processes, including environmental factors (such as children's social economical statuses and support systems). Context variables, such as home and teacher content knowledge and expectations (e.g., Brady & Woolfson, 2008; Buldu, 2010; Depaepe, Verschaffel, & Kelchermans, 2013; Flouri, 2006; Rubie-Davies, 2010) and parental involvement (e.g. Reusser, 2000) should be included in future research.

In-depth studies combining quantitative and qualitative techniques (semi-structured interviews, thematic analyses…) are needed in order to identify possible causes of arithmetic problems and strengths. Future research should address the multidirectional interaction between genetics, cognitive, behavioural and environmental factors.

Although serious games enhanced young children's arithmetic skills, such interventions may be a less promising way of assisting children with mathematical learning disabilities. Additional studies are needed to investigate whether adaptive games, as a core part of the curriculum and preventive support in regular kindergarten classes, can contribute to the realisation of inclusive education (see M-decreet) in primary school.

Finally, when analyses have insufficient power and are not significant, a risk of type 2 or Beta mistakes (concluding from the cohort that there were no differences, although in reality there were differences in the population) could not be excluded. This is why we completed analyses of the total sample instead of one third of the sample (see higher) in chapter 4. However, additional research with larger groups of children comparing, for example, the computerised interventions (CAIs) is indicated.

These limitations indicate that only part of the picture was investigated, so additional studies should focus on these aspects.

However, one of this doctoral research's **strengths** is that all studies were longitudinal studies, which means the results can better address the relationships compared to cross-sectional studies. For instance, one might question if higher levels of language skills lead to better arithmetic skills, or if it is the other way around. As language was assessed in kindergarten and arithmetic in preschool, grade 1 and grade 2 in a large sample of children (n = 132), the impact of language on arithmetic can be better analysed in such a design.
In addition, several predictors were combined in one model, with the unique scientific merit of focusing on age-related changes at five measuring points (from kindergarten to Grade 2). A latent growth curve model was fitted with the intercept as logPAE (accuracy level) and the slope as a linear growth rate. PAEs were log transformed for distributional reasons. This growth model was used to study the changes in relationships between the variables over time.

4. PRACTICAL AND THEORETICAL IMPLICATIONS

Some important implications can be drawn based on the conclusions of this doctoral thesis.

4.1. Language (tested in kindergarten) as a predictor of arithmetic abilities

Expressive language (in chapter 2) explained about one fourth of the unique variance in arithmetic skills among kindergartners. However, in the total sample the core language index was a specific predictor. So assessing language in addition to procedural counting knowledge in order to get a full picture of the arithmetic skills in children seems necessary. The growth model also revealed (in chapter 4) that language particularly influenced the starting point, but not the development, of the number line estimation accuracy. These findings mean language has some additional value in the assessment of children in kindergarten.

In addition, kindergarten teachers focusing on numbers and on the intensified stimulation of language might enhance young children's numerical development. It may be interesting to study whether a language intervention could impact arithmetic skills in grade 1. It may therefore be interesting to add a component (level) to the computerised programme, focusing on number language and investigating whether this adds value to the two other serious games (used in chapter 5). However, classroom teachers should be aware that waiting for problems in grade 1 is a waste of time and a short period of intense gaming in kindergarten might be useful to fill the gap between low performing children (at-risk) and children who are learning spontaneously.

4.2. Estimation as a predictor of arithmetic abilities

Estimation can be tested with a number line estimation paradigm. We demonstrated that the overall estimations become more accurate (lower PAE) when children are older and more familiar with numbers in chapter 4.

There was mixed evidence for estimation's format-independency. In line with the format-independency and studies by Barth, Kanwisher and Spelke (2003), estimations became more accurate in all estimation tasks (using Arabic numerals, number words or dots as formats). However, in contrast with the format-independency, our findings suggested that, at an early age, more children had linear distribution for number words. The number words, in particular, became format-important in grade 2.

In addition, results (chapter 4) revealed a significant logarithmic representation in kindergarten and in grade 1. Children had significant linear representations for number-word estimation at the beginning of grade 2. There were significant linear distributions for Arabic numbers, number words and dots in the middle of grade 2.

The percentage absolute error (PAE) on the 0-100 number line estimation task decreased by 54.9% between the end of kindergarten and the middle of grade 2.

There was significant interindividual variation for the intercept but not for the slope, pointing to significant variability between the children where estimation accuracy (intercepts) is concerned, but not in the evolution of their growth curves. In addition, intelligence explained a significant part of interindividual variability and the slope of the PAE.

There was also a trend in the relationship between untimed calculation skills (start of grade 1) and the PAE with dots and between untimed calculation skills (middle of grade 2) and the PAE of number words.
In line with Sasanguie, Göbel, Moll, Smets, & Reynvoet (2013), no significant relationships were found between linearity and accuracy of estimation and timed arithmetic. The differences between timed and untimed arithmetic demonstrated that arithmetic cannot be seen as a homogeneous ability. This is in line with the findings of Pieters, Roeyers, Rosseel, Van Waelvelde and Desoete, (2013) who showed that MLD may have many predictive components, but lacks a homogeneous disability profile.

These findings mean that number line estimation tasks on a 0-100 scale may have a predictive value for untimed arithmetic (calculation) in grades 1 and 2. It also seems possible to enhance arithmetic in grade 1 by serious counting and comparison games in kindergarten, without children becoming more accurate in the 0-100 number line estimation task in grade 1.

4.3. Serious (counting) games as head-start in kindergarten

We empirically demonstrated the positive results of less than 5 hours of intensive educational /serious gaming in chapter 5.
This is in line with the findings of Lyytinen, Ronimus, Alanko, Poikkeus and Taanila (2007). Children in the counting condition did better than children in the number comparison intervention. Children in both CAI groups had significantly higher calculation scores than children in the control group.

When we look at children with low (< pc 25) and average kindergarten skills, we found that both groups of children (low and average performers) benefitted from the CAI in supporting development of their early numerical skills.

This study confirms the findings of Dowker (2013) and Ramani and Siegler (2008; 2011), that early numeracy can be stimulated in kindergarten, even in low-performers, with a sustained effect on arithmetic in grade 1. This is good news for the M-decreet's aim to include more children in regular schools.
As a consequence, a general kindergartner approach within the '*Universal Design for Learning* (UDL)' seems to be indicated. A UDL framework aims at creating learning environments and adopting teaching materials and practices which allow for participation by all children, regardless of individual learning differences (Hanna, 2005). As such, the UDL principles lend themselves to the implementation of inclusionary practices in general educational settings, because they consist of flexible approaches which can be customised and adjusted for individual needs (Hitchcock, Meyer, Rose, & Jackson, 2002). As per the above mentioned suggestions, also using serious games fits in well with this approach and we will encourage its further development and implementation. The *M-decreet* can help to provide a statutory framework to realise this. A UDL-design will give all children enough time and stimulation, with daily recapping of previously learnt material and an explicit vocabulary building. Low performers do not have to depend on implicit learning in such an approach, but all children

benefit from the adjusted speed and adequate support of early numeracy, using serious games.

In line with the findings of Wilson et al., (2006) and Räsänen et al., (2009) we can conclude that playing educational games may create a buffer against poor arithmetic outcomes. Educational CAI games in kindergarten may ensure the children 'learn' and enjoy connecting new knowledge to prior knowledge. Delaying preventive interventions until grade 1 may be a waste of time, as a short period of intense and adaptive gaming with counting games in kindergarten revealed it filled the gap between at-risk children and children who are learning spontaneously.

CONCLUSION

As language is a largely unexplored research domain in children in the prediction of arithmetic proficiency, providing an increased insight into the relationship between young children's early numerical competencies and language abilities was the starting point of this doctoral research. Overall, we can conclude that language, as an early numerical competency, has some additional value in the prediction of children's untimed calculation abilities. In addition, serious games in kindergarten can enhance the evolution of arithmetic skills in grade 1 without number line estimation becoming more accurate.

As such, we recommend creating language stimulating learning environments and using serious counting games and other attractive teaching materials to increase opportunities for all children (including the group of poor performers in line with the *M-decreet*), as conceptualised within the *Universal Design for Learning (UDL)* framework. With regard to the prediction of arithmetic in primary school children, language measures, given their substantial predictive value, should be included in assessments at kindergarten level.

Although this doctoral dissertation extends the limited information available on the prediction of young children's arithmetic abilities, many questions remain unanswered. We therefore encourage future research, allowing for further steps to be taken in unravelling this complex puzzle by integrating different perspectives, in order to optimise young children's learning environments.

References

Ansari, D., Donlan, C., Thomas, M. S.C., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology*, 85, 50–62. http://dx.doi.org/10.1016/S0022-0965(03)00026-2.

Ashcraft, M. H., & Moore, A. M. (2012). Cognitive processes of numerical estimation in children. *Journal of Experimental Child Psychology, 111*, 246-267. http://dx.doi.org/10.1016/j.jecp.2011.08.005

Aunola, K., Leskinen, E., Lerkkanen, M. -K., & Nurmi, J. -E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96(4)*, 699-713. http://dx.doi.org/10.1037/0022-0663.96.4.699

Barner, D., Chow, K., & Yang, S. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58,* 195-219. http://dx.doi.org/10.1016/j.cogpsych.2008.07.001

Baudonck, M., Debusschere, A., Dewulf, B., Samyn, F., Vercaemst, V., & Desoete, A. (2006). *Kortrijke Rekentest Revisie(KRT-R)[Kortrijk Arithmetic Test Revision]*. Kortrijk: Revalidatiecentrum Overleie.

Barth, H., Kanwisher, N., & Spelke, E. (2003). The construction of large number representation in adults. *Cognition, 86,* 201-221. http://dx.doi.org/10.1037/a0013046

Buldu, M. (2010). Making learning visible in kindergarten classrooms: Pedagogical documentation as a formative assessment technique. *Teaching and Teacher Education, 26(8),* 1439-1449. http://dx.doi.org/10.1016/j.tate.2010.05.003

Bertelli, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers *Developmental Psychology, 46,* 545-551. http://dx.doi.org/10.1037/a0017887.

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology, 42,* 189–201. http://dx.doi.org/10.1037/ 0012-1649.41.6.189.

Brady, K., & Woolfson, L. (2008). What teacher factors influence their attributions for children's difficulties in learning? *British Journal of Educational Psychology, 78(4)*, 527 -544. http://dx.doi.org/10.1348/000709907X268570

Canobi, K. H., & Bethune, N. E. (2008). Number words in young children's conceptual and procedural knowledge of addition, subtraction and inversion. *Cognition, 108,* 675–686. http://dx.doi.org/10.1016/j.cognition.2008.05.011.

Cowan, R., & Renton M. (1996). Do they know what they are doing? Children's use of economic addition strategies and knowledge of commutativity. *Educational Psychology, 16,* 407-420 . http://dx.doi.org/10.1080/0144341960160405

Dawson, R. (2003). Early math strategy: the report of the expert panel on early math in Ontario. Ontario, Ontario Ministery of Education., Government of British Columbia, 2003

Dehaene, S., Izard, V., & Piazza, M. (2005). Control over non-numerical parameters in numerosity experiments. Unpublished manuscript (available at http://www.unicog.org/…/DocumentationDotsGeneration.doc).

Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge : A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education, 34* (August 2013) 12-25. http://dx.doi.org/10.1016/j.tate.2013.03.001

De Vos, T. (1992). *Tempo Test Rekenen [Arithmetic Number Facts Test]*. Nijmegen, The Netherlands: Berkhout.

Dowker, A.D. (2005). Individual differences in arithmetic. Implications for psychology, neuroscience and education. New York: Psychology Press

Dowker, A. (2013). *Interventions for children with mathematical difficulties*. Paper EARLI conference August 27th Munchen.

Fischer, B., Gebhardt, C., & Hartnegg, K. (2008). Subitizing and visual counting in children with problems acquiring basic arithmetic skills. *Optometry and Vision Development, 39,* 24–29 (Retrieved from http://www.covd.org/Portals/0/24-29SubitizingVisualCounting. pdf).

Flemish Ministry of Education and Training. (2014). Special educational needs. from http://www.ond.vlaanderen.be/specifieke-onderwijsbehoeften/

Flouri, E. (2006). Parental interest in children's education, children's self-esteem and locus of control, and later educational attainment: Twenty-six year follow-up of the 1970 British birth cohort. *British Journal of Educational Psychology, 76(1),* 41-55. http://dx.doi.org/10.1348/000709905X52508

Geary, D. C. (2011). Consequences, characteristics, and causes of poor mathematics achievement and mathematical learning disabilities. *Journal of Developmental and Behavioral Pediatrics, 32,* 250-263. http://dx.doi.org/10.1097/DBP.0b013e318209edef

Geary, D. C., Hoard, M. K., Nugent, L., & Byrd-Craven, J. (2008). Development of number line representations in children with mathematical learning disability. *Developmental Neuropsychology, 33*, 277-299. http://dx.doi.org/10.1080/87565640901982361

Grégoire, J., Noël, M., & Van Nieuwenhoven (2004). TEDI-MATH. Antwerpen: Harcourt.

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the "number sense": The approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology, 44*, 1457–1465. http://dx.doi.org/10.1037/a0012682.

Hanna, E. I. (2005). *Inclusive design for maximum accessibility: A practical approach to universal design (PEM Research Report No. 05-04).* Upper Saddle River, NJ: Pearson Educational Measurement.

Hannula, M. M., Räsänen, P., & Lehtinen, E. (2007). Development of counting skills: Role on numerosity and subitizing-based enumeration. *Mathematical Thinking, 9,* 51–57. http://dx.doi.org/10.1080/10986060709336605.

Heim, S., Amunts, K., Drai, D., Eickhoff, S. B., Hautvast, S., & Grodzinksy, Y. (2012). The language-number interface in the brain: A complex parametric study of quanti- fiers and quantities. *Frontiers in Evolutionary Neuroscience, 4.* http://dx.doi.org/ 10.3389/fnevo.2012.00004 (Article 4, 12 pp.).

Hitchcock, C. G., Meyer, A., Rose, D., & Jackson, R. (2002). Providing new access to the general curriculum: Universal design for learning. *Teaching Exceptional Children*, *35*, 8-17.

Inglis, M., Attridge, N., Batchelor, S., & Gilmore, C. (2011). Non-verbal number acuity cor- relates with symbolic mathematics achievement: But only in children. *Psychonomic Bulletin Review, 18*, 1222–1229. http://dx.doi.org/10.3758/s13423-011-0154-1.

Kucian, K., Grond, U., Rotzer, S., Henzi, B., Schonmann, C., Plangger, F., . . . von Aster, M. (2011). Mental number line training in children with developmental dyscalculia. *Neuroimage, 57*, 782-795. http://dx.doi.org/10.1016/j.neuroimage.2011.01.070

Levine, S.C., Jordan, N. C., & Huttenlocher, J. (1992). Development of calculation abilities in young children. *Journal of Experimental Child Psychology*, *53*, 72–103. http://dx.doi.org/10.1016/j.cognition.2008.05.011.

Lyytinen, H., Ronimus, M., Alanko, A., Poikkeus, A., & Taanila, M. (2007). Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psychology*, *59(2)*, 109-126. http://dx.doi.org/10.1027/1901-2276.59.2.109

Morton J., & Frith, U.(1995).Causal modelling: A structural approach to developmental psychopathology. In D. Cicchetti & D.J. Cohen (Eds). Developmental psychopathology (Vol1: Theory and methods, pp 357-390). New York: Wiley

Heim, S., Amunts, K., Drai, D., Eickhoff, S. B., Hautvast, S., & Grodzinksy, Y. (2012). The language-number interface in the brain: A complex parametric study of quanti- fiers and quantities. *Frontiers in Evolutionary Neuroscience, 4.* http://dx.doi.org/ 10.3389/fnevo.2012.00004 (Article 4, 12 pp.).

Negen, J., & Sarnecka, B. W. (2012). Number-concept acquisition and general vocabulary de- velopment. *Child Development.* http://dx.doi.org/10.1111/j.1467-8624.2012.01815.x.

Patel, P & Canobi K.H. (2010) The role of number words in preschoolers' addition concepts and problemsolving procedures, *Educational Psychology: An International Journal of Experimental Educational Psychology,* 30:2, 107-124, http://dx.doi.org/ 10.1080/01443410903473597

Pieters, S., Roeyers, H., Rosseel, Y., Van Waelvelde, H., & Desoete, A. (2013). Identifying subtypes among children with developmental coordination disorder and mathematical learning disabilities, using model-based clustering. *Journal of learning disabilities.* http://dx.doi.org/10.1177/0022219413491288

Praet, M., & Desoete, A. (2014a). Enhancing young children's arithmetic skills through not-intensive, computerised kindergarten interventions: a randomised controlled study,*Teacher and Teacher Education*, 39, 56-65. http://dx.doi.org/10.1016/j.tate.2013.12.003

Praet, M. & Desoete, A. (2014b). Number line estimation from kindergarten to grade 2: a longitudinal study. Learning and Instruction, 01,(33), 19–28. http://dx.doi.org/10.1016/j.learninstruc.2014.02.003

Praet, M., Titeca, D., Ceulemans, A., & Desoete, A. (2013). Language in the prediction of arithmetics in kindergarten and grade 1. *Learning and Individual Differences, 27*, 90-96. http://dx.doi.org/10.1016/j.lindif.2013.07.003

Praet, M., & Desoete, A. (2013). Number Sense in Siblings of Children with Mathematical Learning Disabilities: A Longitudinal Study, *Journal of Intellectual Disability - Diagnosis and Treatment, 1(1),* 67-73,http://dx.doi.org/10.6000/2292-2598.2013.01.01.8

Räsänen, P., Salminen, J., Wilson, A.J., Aunio, P., & Dehaene, S. (2009). Computer-assisted intervention for children with low numeracy skills. *Cognitive Development, 24(4),* 450-472. http://dx.doi.org/10.1016/j.cogdev.2009.09.003.

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development, 79(2)*, 375-394. http://dx.doi.org/10.1111/j.1467-8624.2007.01131.x

Ramani, G. B., & Siegler, R. S. (2011). Reducing the gap in numerical knowledge between low- and middle-income preschoolers. *Journal of Applied Developmental Psychology, 32(3),* 146-159. http://dx.doi.org/10.1016/j.appdev.2011.02.005

Reusser, K. (2000). Success and failure in school mathematics: Effects of instruction and school environment. *European Child & Adolescent Psychiatry, 9,* II/7–II/26.

Rubie-Davies, C. M., & Peterson, E. (2010). Teacher expectations and beliefs: Their influence on the socioemotional environment of the classroom. In Rubie-Davies, C. M. (Ed.) *Educational Psychology: Concepts, research and challenges* (pp. 134-149). Routledge: London.

Sasanguie, D., Göbel, S.M., Moll, K., Smets, K., & Reynvoet, B. (2013). Approximate number sense, symbolic number processing, or number-space mappings: What underlies mathematics achievement? *Journal of Experimental Child Psychology, 114,* 418-431. http://dx.doi.org/10.1016/j.jecp.2012.10.012.

Semel, E., Wiig, E. H., & Secord, W. A. (2008). *CELF 4 Nl Clinical Evaluation of Language Fundamentals.* Amsterdam: Pearson.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75*, 428-444. http://dx.doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science, 14*, 237-243. http://dx.doi.org/10.1111/1467-9280.02438

Siegler, R. S., & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science, 11*, 655-661. http://dx.doi.org/10.1111/j.1467-7687.2008.00714.x

Stock, P., Desoete, A., & Roeyers, H. (2009). Mastery of the counting principles in toddlers: A crucial step in the development of budding arithmetic abilities? *Learning and Individual Differences, 19(4),* 419-422. http://dx.doi.org/10.1016/j.lindif.2009.03.002

Stock, P., Desoete., & Roeyers. (2010). Detecting Children With Arithmetic Disabilities From Kindergarten: Evidence From a 3-Year Longitudinal Study on the Role of Preparatory Arithmetic Abilities. *Journal of Learning Disabilities, 43*, 250 - 268. http://dx.doi.org /10.1177/0022219409345011

Sylvia, K. (2009). *Early childhood matters:* Evidence from the effective preschool and primary education project London: Taylor and Francis.

Wilson, A. J., Revkin, S.K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of "The Number Race", an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions, 2* (20). http://dx.doi.org/10.1186/1744-9081-2-20.

NEDERLANDSTALIGE SAMENVATTING

Wanneer een eerste klasser op 1 september begint aan een 12-jarige schoolcarrière, heeft hij zich reeds een aanzienlijk aantal rekenkundig vaardigheden eigen gemaakt. Meestal zijn de problemen die zich voordoen bij het doorlopen van het eerste leerjaar, terug te brengen naar tekorten die reeds aanwezig waren in de derde kleuterklas. Wordt de kleuter alsdan reeds herkend en erkend als zijnde een 'risico-kind op het ontwikkelen van een vertraagde rekenontwikkeling' dan kan een vroegtijdige interventie nog uitkomst bieden om aansluiting te vinden vòòr de aanvang van het feitelijk rekenonderwijs. Risicokleuters kunnen vroegtijdig als dusdanig gesignaleerd worden door hun voorbereidende rekenvaardigheden in kaart te brengen. Een aantal van deze risicosignalen werden reeds in vroeger onderzoek aan het licht gebracht. Het gaat hier om de deelvaardigheden tellen, kennen van numerieke symbolen en het vergelijken van hoeveelheden. Om succesvol het eerste leerjaar te doorlopen moet het kind deze vaardigheden bezitten. Voor de meerderheid van de kinderen is dit een natuurlijk gegeven dat aansluit bij hun vaardigheden die zij via hun spel (thuis en op school) hebben verzameld.

Deze doctoraalthesis heeft tot doel een aantal minder onderzochte grondpijlers van het rekenen in kaart te brengen en de relatie met de reeds onderzochte parameters te verduidelijken. We volgen daarom de rekenkundige ontplooiing en de deelvaardigheden van 132 kinderen in de overgang van de derde kleuterklas tot het tweede leerjaar. Daarnaast werd tot op heden, de relatie taal - rekenen nauwelijks onderzocht. Ook hieromtrent lag het in onze bedoeling extra accenten aan te brengen.

Tot slot wilden we nagaan of preventieve instructie in de kleuterklas ervoor kan zorgen dat kinderen in het eerste leerjaar beter gaan rekenen en dat risicokleuters alsnog aansluiting vinden met leeftijdsgenoten waar dit alles vlotter verloopt, vòòr de aanvang van het formele rekenonderwijs. Indien dit het geval is kunnen meer kinderen, zoals het M-decreet wil, in het gewone onderwijs les blijven volgen.

Voornaamste onderzoeksresultaten

Dat verschillende vaardigheden een voorspellende waarde hebben voor het rekenen werd reeds meermaals aangetoond (o.m. Aunio & Niemivirta, 2010; Dowker, 2005; Kroesbergen, Van Luit, & Aunio, 2012; Mayes, Calhoun, Bixler, & Zimmerman, 2009). In dit onderzoek hebben wij getracht deze predictoren te combineren en ook taal als predictor in rekening te brengen.

Taal als voorspeller van rekenen

Op basis van 'benoemen van cijfers' en 'procedureel rekenen' bleek het mogelijk de variantie van het rekenen voor 24% door de expressieve taal te verklaren. Maar daarenboven bleek dat de voorbereidende rekenvaardigheid in in de derde kleuterklas ook een voorspellende functie te hebben voor het rekenen van kinderen in het eerste leerjaar. Zo kon tot 29,9% van de rekenkundige variantie in het eerste leerjaar voorspeld worden. Taal had dan nòg een additieve bijdrage van 4,6% in de voorspelling van het rekenen in het eerste leerjaar (Praet, Titeca, Ceulemans, & Desoete, 2013).

Het is kan dus waardevol zijn om bij risicokinderen, waaronder de brussen (broer en zussen) van kinderen met een rekenstoornis (Desoete, Praet, Titeca, & Ceulemans, 2013) ook taal te onderzoeken wanneer de voorbereidende rekenvaardigheden in kaart gebracht worden.

In hoofdstuk 4 werd onderzocht hoe kinderen Arabische getallen, getalwoorden en stippen konden situeren/schatten op een getallenas ('number line'). Er werd een groeimodel geconstrueerd. Hierbij bleek dat het startpunt beïnvloed werd door taal maar dat taal niet bepaalde hòè de number line verder evolueerde. Er kon ook geen relatie aangetoond worden met de evolutie in het meer accuraat (percentage abolute error of PAE) worden van de schattingen. Deze bevindingen zijn congruent met de onderzoeksresultaten van Ansari, Donlan, Thomas, Ewing, Peen en Karmiloff-Smith (2003).

De getallenastaak als predictor van het vaardig rekenen.

We testten het plaatsen van getalwoorden, Arabische getallen en een hoeveelheid stippen op een 0-100 getallenas. Het interpreteren van de resultaten gebeurde door na te gaan hoeveel procent fouten er gemaakt werden (PAE) bij het plaatsen, door na te gaan of kinderen evenveel fouten maakten in alle modaliteiten (getalwoorden, Arabische getallen en stippen) , door de lineariteit van de kurve en door de groeikurve te evalueren.

Hieruit bleek dat schattingen 'waar een hoeveelheid zich bevindt' op een getallenlijn steeds nauwkeuriger (lagere PAE) worden naarmate het kind ouder én meer vertrouwd wordt met de hoeveelheden die het moet inschatten. Het percentage fouten (PAE) nam sterk af tussen de kleuterklas en het eerste leerjaar. Bij de overgang tussen eerste leerjaar-tweede leerjaar was die daling veel minder prominent.

Er was een modaliteits-onafhankelijkheid te zien in onze dataset. De schatting in de drie modaliteiten: het getalwoord (symbolisch), het Arabisch cijfer (symbolisch) en de hoeveelheid stippen (asymbolisch) werden steeds nauwkeuriger weergegeven (lagere PAE) over het verloop van tijd. Het onderzoek van Barth, Kanwisher en Spelke (2003) had het reeds over een modaliteits-onafhankelijkheid.

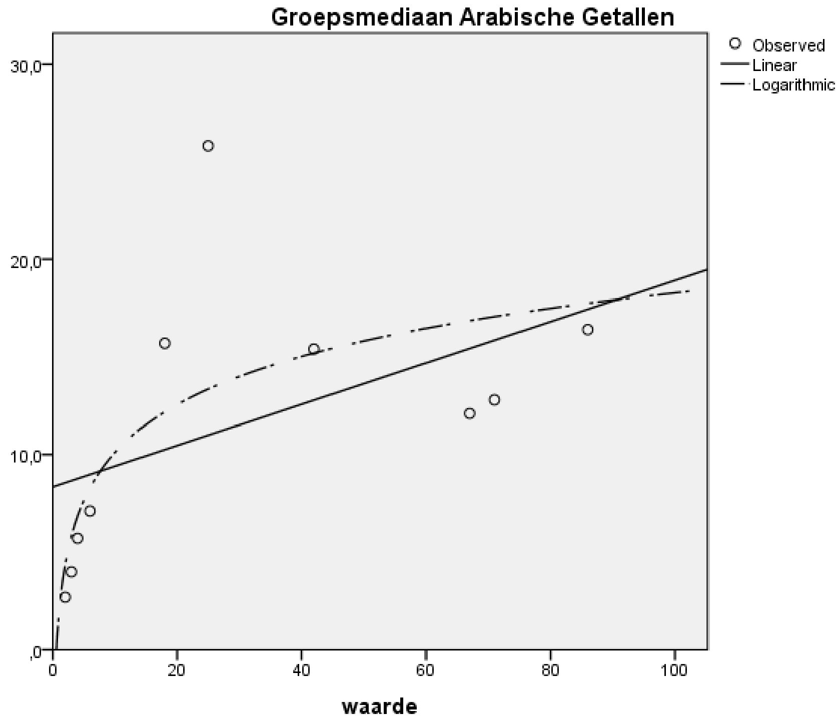
We bestudeerden ook de aard van **de distributie of de lineariteit en de accuraatheid (of de PAE) van de representaties op een getallenas 0-100.**

Om de distributie van de representaties te kennen werd de mate van lineariteit van hun representaties (R^2_{lin}) bepaald voor alle kinderen (op groepsniveau) van 3de kleuter tot 2de leerjaar. Daarnaast werd ook per kind (op individueel niveau) nagegaan hoe de evolutie plaats vond.

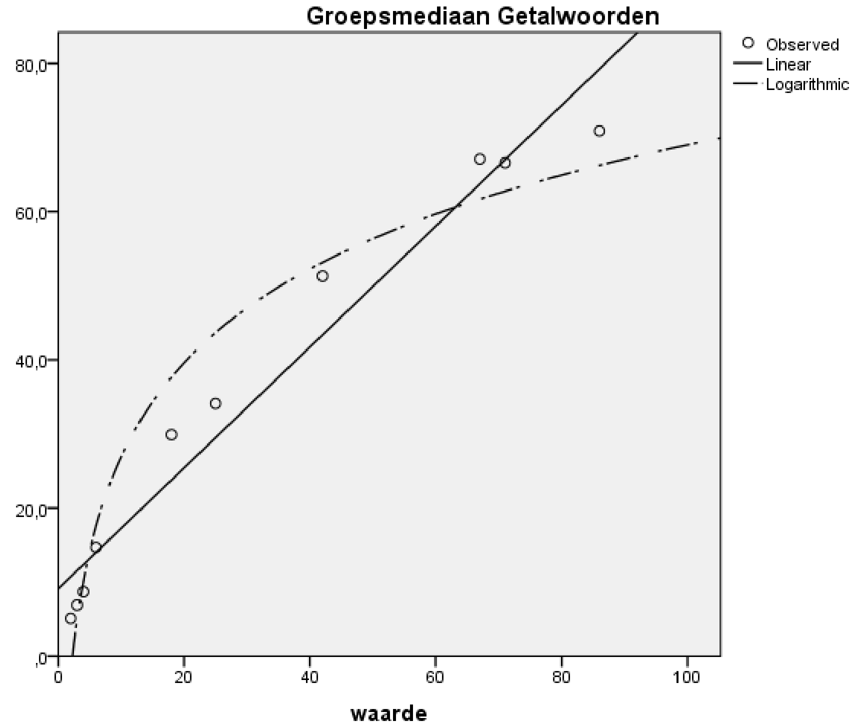
Lineariteit van de ***representatie op groepsniveau:***

In de derde kleuterklas en in het eerste leerjaar was er een significante logarithmische representatie voor alle modaliteiten (Arabische getallen (zie Figuur 1), getalwoorden (zie Figuur 2) en hoeveelheden (zie Figuur 3)).

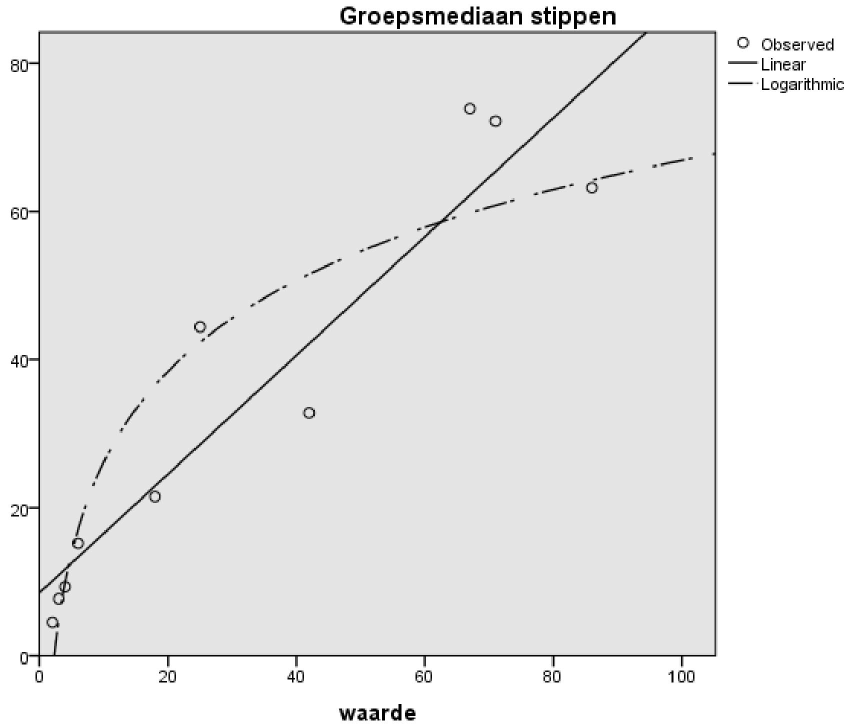
Figuur 1:



Figuur 2:


Groepsmediaan Getalwoorden
Observed
Linear
Logarithmic
80,0
60,0
40,0
20,0
,0
0
20
40
60
80
100
waarde

Figuur 3:



In het begin van het tweede leerjaar wordt er voor de getalwoorden een significante lineaire representatie waargenomen. In het midden van het tweede leerjaar worden ook Arabische cijfers en hoeveelheden significant lineair voorgesteld.

Lineariteit van de ***representatie op individueel niveau***:

In de derde kleuterklas zagen we bij alle modaliteiten dat kleuters alles (Arabische cijfers, getalwoorden en stippen) logarithmisch of 'niet' consequent bepaalden (Praet & Desoete, 2014b).

Anderhalf jaar later, bij het begin van het tweede leerjaar (graad 2), had al meer dan 50% van de kinderen een lineaire representatie van Arabische getallen op dezelfde getallenas van 0-100. Dit was ook zo voor 41,7% van de kinderen bij het schatten van getalwoorden en voor 46,7% van de kinderen bij het schatten van de waarde van een hoeveelheid stippen op dezelfde getallenas.

In het midden van de tweede leerjaar had 60% van de kinderen een lineaire representatie hadden in alle modaliteiten.

Accuraatheid van de representatie

Wanneer we naar de accuraatheid (Percentage Absolute Error of PAE) gingen kijken op het groeimodel zagen we dat de fouten (PAE) verminderden met 54,9% tussen de derde leuterklas en het midden van het tweede leerjaar. Kinderen gingen dus steeds nauwkeuriger schatten waar een Arabisch getal, getalwoord of hoeveelheid stippen zich situeerde op een getallenas van 0-100.

De groeikurve maakte ook duidelijk dat er naar nauwkeurigheid toe tussen de kinderen onderling heel veel variatie bestond van bij de start. Er was minder variatie in de evolutie van het schatten. De interindividuele variabliteit kon voor een deel verklaard worden vanuit de verschillen in intelligentie. Intelligentie verklaarde ook de graad van afname van de PAE.

Tenslotte gingen we na of de lineariteit en de accuraatheid van de representaties op een getallenas 0-100 gerelateerd was aan het vaardig rekenen van kinderen.

We onderzochten het verband tussen prenumerische vaardigheden (in de kleuterklas), de numerische vaardigheden (het rekenen met en zonder tijdsdruk in het 1ste en 2de leerjaar) en nauwkeurigheid (PAE) en mate van lineariteit (R^2_{lin}) bij het schatten (in de drie modaliteiten) op een 0-100 getallenas. Dit werd aangekaart in hoofdstuk 5.

Wat betreft accuraatheid was er in de kleuterklas een significante relatie tussen de prenumerische of voorbereidende rekenvaardigheden van kinderen en het percentage fouten (PAE) die ze maakten op de getallenas van 0-100 in de modaliteit met Arabische getallen.
Het begin van het eerste leerjaar was er een trend van relatie tussen rekenen zonder tijdsdruk en het accuraat schatten van hoeveelheden (PAE). In het midden van het tweede leerjaar was er een trend tussen rekenen zonder tijdsdruk

en accuraat schatten (PAE) van getalwoorden. Er was geen relatie tussen PAE en temporekenen.

Wat betreft de lineariteit vonden we op het eind van eerste leerjaar en in het midden tweede leerjaar een significante relatie tussen mate van lineariteit en rekenen zonder tijdsdruk. Er was echter geen relatie tussen lineariteit en het ophalen van rekenfeiten uit het geheugen ook wel temporekenen (of rekenen met tijdsdruk) genoemd.

Het niet vinden van een relatie tussen lineariteit van representatie en temporekenen is in overeenstemming met de studie van Sasanguie, Göbel, Moll, Smets en Reynvoet (2013) die evenmin zo'n significante relatie tussen mate van lineariteit en het ophalen van rekenfeiten vonden. Het verschil tussen rekenen met én zonder tijdsdruk toont eveneens aan dat rekenen geen homogeen gegeven is. Dit bevestigt de bevindingen van Pieters, Roeyers, Rosseel, Van Waelvelde en Desoete (2013). De studie van Pieters et al. (2013) toonde aan dat er subtypes zijn waarbij sommige kinderen met dyscalculie uitvallen op temporekenen en op rekenen zonder tijdsdruk (semantische geheugen dyscalculie), terwijl anderen enkel uitvallen op rekenen zonder tijdsdruk (procedurele dyscalculie).

De interventies die een invloed hebben op het rekenen

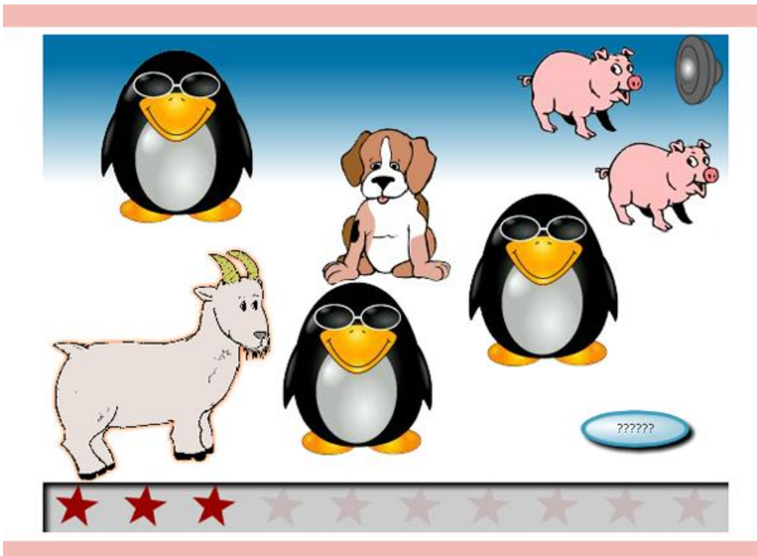
In hoofdstuk 5 vroegen we ons af of acht computergestuurde adaptive interventies van 25 minuten in de kleuterklas konden helpen om kinderen een jaar later (in het eerste leerjaar) beter te doen rekenen (Praet & Desoete, 2014a).

We zetten dit onderzoek op naar analogie van bevindingen bij iets oudere kinderen (Räsänen Salminen, Wilson, Aunio, & Dehaene, 2009; Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006). We vergeleken twee computer gestuurde interventies: de ene interventiegroep focuste op tellen, de andere interventiegroep focuste op vergelijken. We onderzochten of kinderen in die interventies beter konden rekenen dan kinderen die geen interventie kregen.

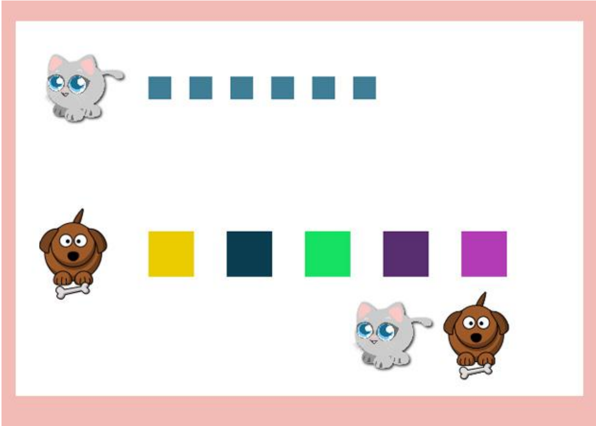
Daarnaast wilden we nagaan welke van de twee instructievarianten het meest effectief was op korte termijn (in de kleuterklas) en een jaar later (in het eerste leerjaar).

Empirisch werd aangetoond dat intensief gamen (met educatieve software in beide condities) gedurende minder dan 300 minuten ertoe kon bijdragen dat kinderen beter gingen rekenen. De tijd die besteed werd in de kleuterklas aan het ‘oefenen’ rendeerde ook als ‘voorsprong’-benadering bij zwakkere kleuters. Dit bevestigt de bevindingen van Lyytinen, Ronimus, Alanko, Poikkeus en Taanila (2007).

Wanneer er geëvalueerd werd welke aanpak nu de beste was (oefenen op tellen (zie Figuur 4) of oefenen op vergelijken (zie Figuur 5), dan bleek dat kinderen uit de ‘tel’-groep het beter deden dan de kinderen uit de ‘vergelijkings’-groep. Maar de beide experimentele groepen deden het significant beter voor rekenen dan de controlegroep.



Figuur 4: Oefening op tellen



Figuur 5: Oefening op vergelijken

De interventie was ook effectief bij de kinderen die laag of gemiddeld scoorden als kleuter qua voorbereidende rekenvaardigheden. Een computer gestuurde (CAI) interventie voor kinderen met zwakke prenumerische vaardigheden opzetten, leek in staat om hun 'gecijferdheid' aan te wakkeren. We konden er met de interventie zelfs voor zorgen dat de zwakke leerlingen die een interventie kregen, beter konden rekenen dan de goede leerlingen die géén interventie kregen in de kleuterklas. In aansluiting met de bevindingen van Dowker (2013) en Ramani en Siegler (2008; 2011) kunnen we dus besluiten dat prenumerische vaardigheden kunnen getraind worden in de kleuterklas en dit zelfs bij zwakke (of risico) kleuters. In overeenstemming met de bevindingen van Wilson et al. (2006) en Räsänen et al. (2009) kunnen we concluderen dat een korte interventie op het leren tellen en/of vergelijken van hoeveelheden als buffer (of voorsprongs-benadering) kan functioneren voor het risicokind met verminderde voorbereidende rekenvaardigheden (Praet & Desoete, 2014).

Besluiten

De studies in dit proefschrift boden ons een beter inzicht in de relatie tussen taal, het schatten en rekenen in de basisschool. Bovendien toonden we aan dat we met een korte periode van oefenen met de computer (gaming) in de kleuterklas kinderen een voorsprong kunnen geven in het rekenen in het lste leerjaar. Dit proefschrift bood ook een beter inzicht in de studies rond symbolische en asymbolische getallenastaken (PAE) en neariteit. Het pleit ook tot vervolgonderzoek bij kinderen met dyscalculie. Bij een vervolgonderzoek is het aangewezen om ook school en sociale factoren mee te nemen in de verklaring van de rekenvaardigheden van kinderen. Ondanks dit onderzoek blijven vragen bestaan rond de soort rekentaken (rekenen met en zonder tijdsdruk) de etiologie van atypische rekenontwikkeling en de effectieve interventies om kinderen beter te doen rekenen.

Referenties

Ansari, D., Donlan, C., Thomas, M. S.C., Ewing, S. A., Peen, T., & Karmiloff-Smith, A. (2003). What makes counting count? Verbal and visuo-spatial contributions to typical and atypical counting development. *Journal of Experimental Child Psychology*, 85, 50–62, http://dx.doi.org/10.1016/S0022-0965(03)00026-2.

Aunio, P., & Niemivirta, M. (2010). Predicting children's mathematical performance in grade one by early numeracy. *Learning and Individual Differences, 20,* 427–435, http://dx.doi.org/10.1016/j.lindif.2010.06.003.

Desoete, A., Praet, M., Titeca, D., & Ceulemans, A. (2013). Cognitive phenotype of mathematical learning disabilities: What can we learn from siblings? *Research in Developmental Disabilities, 34,* 404–412, http://dx.doi.org/10.1016/j.ridd.2012.08.022.

Dowker, A.D. (2005). Individual differences in arithmetic. Implications for psychology, neuroscience and education. New York: Psychology Press

Dowker, A. (2013). *Interventions for children with mathematical difficulties*. Paper EARLI conference August 27th Munchen.

Kroesbergen, E. H., Van Luit, J. E. H., & Aunio, P. (2012). Mathematical and cognitive pre- dictors of the development of mathematics. British *Journal of Educational Psychology, 82*, 24–27, http://dx.doi.org/10.1111/j2044-8279.2012.02065.x.

Lyytinen, H., Ronimus, M., Alanko, A., Poikkeus, A., & Taanila, M. (2007). Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psycholgy, 59(2),* 109-126. http://dx.doi.org/10.1027/1901-2276.59.2.109

Mayes, S.D., Calhoun, S. L., Bixler, E. O., & Zimmermann, D.N. (2009). IQ and neuropsychological predictors of academic achievement.. *Learning and Individual Differences 19,* 238-241. http://dx.doi.org/10.1016/j.lindif.2008.09.001

Pieters, S., Roeyers, H., Rosseel, Y., Van Waelvelde, H., & Desoete, A. (2013). Identifying subtypes among children with developmental coordination disorder and mathematical learning disabilities, using model-based clustering. *Journal of learning disabilities.* http://dx.doi.org/10.1177/0022219413491288

Praet, M., Titeca, D., Ceulemans, A. & Desoete A. (2013). Language in the prediction of arithmetics in kindergarten and grade 1.Learning and Individual Differences (Impact Factor: 1.58). 01/2013; 27:90-96. http://dx.doi.org/10.1016/j.lindif.2013.07.003

Praet, M., & Desoete, A.(2014a) .Enhancing young children’s arithmetic skills through non-intensive, computerised kindergarten interventions: A randomised controlled study *Teaching and Teacher Education*, 39 (2014) 1-10. http://dx.doi.org/10.1016/j.tate.2013.12.003

Praet, M. & Desoete, A. (2014b). Number line estimation from kindergarten to grade 2: a longitudinal study. Learning and Instruction, 01,(33), 19–28. http://dx.doi.org/10.1016/j.learninstruc.2014.02.003

Räsänen, P., Salminen, J., Wilson, A.J., Aunio, P., & Dehaene, S. (2009). Computer-assisted intervention for children with low numeracy skills. *Cognitive Development, 24(4)*, 450-472. http://dx.doi.org/10.1016/j.cogdev.2009.09.003.

Sasanguie, D., Göbel, S.M., Moll, K., Smets, K., & Reynvoet, B. (2013). Approximate number sense, symbolic number processing, or number-space mappings: What underlies mathematics achievement? *Journal of Experimental Child Psychology, 114,* 418-431. http://dx.doi.org/10.1016/j.jecp.2012.10.012.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development, 75*, 428-444. http://dx.doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, *14*, 237-243. http://dx.doi.org/10.1111/1467-9280.02438

Wilson, A. J., Revkin, S.K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of "The Number Race", an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions, 2* (20). http://dx.doi.org/10.1186/1744-9081-2-20.

.