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## An early numeracy intervention for first-graders at risk for mathematical learning difficulties



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### ABSTRACT

The aim of this study was to investigate whether early numeracy skills of South African first graders who are at-risk for mathematical learning difficulties can be improved with an intervention program. The participants were 267 children from 17 classrooms in the greater Johannesburg area. In this quasi-experimental small group intervention study (15 sessions over 5 weeks) the outcome measure was early numeracy skills. Based on pretest early numeracy scores, the children were divided into an intervention group ( $N = 40$ ), a low performing control group ( $N = 32$ ), and an average performing control group ( $N = 195$ ). The main result was that the intervention group had improved more in numerical relational skills, compared to low-controls; this effect remained statistically significant after controlling for executive functions, language skills and kindergarten attendance, and was also observable in the delayed post-measurement. Executive functions, language skills and kindergarten attendance all predicted the level of early numeracy skills at the beginning of the intervention, but only executive functions explained individual differences in counting skills development from pre- to delayed posttest.

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## 1. Introduction

Mathematical skills are important, not only for school performance, but also for children's future educational attainment (Korhonen, Linnanmäki, & Aunio, 2014; Widlund, Tuominen, Tapola, & Korhonen, 2020). Weak early numeracy skills are also a key indicator of later mathematical learning difficulties (Duncan et al., 2007). According to authors such as Dennis et al. (2016) and Mononen, Aunio, Koponen, and Aro (2014), interventions based on research evidence can alleviate the challenges of students at risk for mathematical learning difficulties. Most of these studies have been conducted in resource-rich countries, while studies in developing countries are rare (JET Education Services & Kelelo Consulting, 2018). Furthermore, important factors related to early numeracy development, such as language skills (Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010), executive functions (Morgan et al., 2019), and prior education (Melhuish et al., 2013), may exert confounding effects on the intervention. And yet, these factors

have rarely been included in early numeracy intervention studies (Bryant et al., 2019). In addition, early numeracy interventions have seldom used delayed posttest designs in their experimental studies. One of the few exceptions is the study of Dyson, Jordan and Glutting (2011), which reported important long-term effects on numeracy learning. To address such research gaps, the current study investigated an early numeracy intervention program's effect on South African first-graders at risk for mathematical learning difficulties while controlling for possible confounding variables (executive functions and language skills, kindergarten attendance). A quasi-experimental pre-, immediate- and delayed posttest design was used to provide long term evidence on an early numeracy intervention. Furthermore, the effects of executive functions and language skills on growth in early numeracy skills were also investigated.

### 1.1. Early Numeracy

Early numeracy includes several skills which are important for later mathematics learning (Aunio & Räsänen, 2015; Merkley & Ansari, 2016). More specifically, understanding the mental number line and differences in magnitudes (Merkley & Ansari, 2016; Muldoon, Towse, Simms, Perra, & Menzies, 2013; LeFevre et al., 2010), recognition and naming of number symbols (Göbel, Watson, Lervåg, & Hulme, 2014; Pinto, Bigozzi, Tarchi, Vezzani,

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& Accorti Gamannossi, 2016), numerical relational- and counting skills (Aunio & Niemivirta, 2010; Purpura & Reid, 2016), cardinal knowledge (Chu, VanMarle, & Geary, 2015), basic addition and subtraction skills, and early arithmetical word problem solving skills (Jordan, Glutting, & Ramineni, 2010) have all been found to predict later mathematics performance. Low early numeracy performance is also a potential indicator for later mathematical learning difficulties (Morgan, Farkas, & Wu, 2011; Jordan, Kaplan, Oláh, & Locuniak, 2006; Morgan, Farkas, & Wu, 2009). Such low early numeracy performance can, for instance, be observed during children's regular classroom activities as weak counting skills (e.g. recite number word sequence, enumerate) (Aunio & Niemivirta, 2010), weak numerical relational skills (e.g. compare, seriate) (Purpura & Reid, 2016; Toll & Van Luit, 2014), and weak basic arithmetic skills (Desoete, Stock, Schepense, Baeyens, & Roeyers, 2009; Jordan et al., 2006). Both the operationalization and cut-off scores that are used to define mathematical learning difficulties vary across studies. Studies that have defined mathematical learning difficulties broadly to also include students that are at-risk for mathematical learning difficulties, have generally used cut-off scores between 25% and 50% (Bryant et al., 2019; Geary, 2013; Toll & Van Luit, 2014). Furthermore, longitudinal studies that have used model-based clustering have found that roughly 30% of children in primary school have mathematical learning difficulties (Jordan et al., 2006; Zhang et al., 2020).

## 1.2. Interventions for Children with Mathematical Learning Difficulties

Although many studies have reported positive intervention effects for students with learning difficulties in mathematics (Coding, Burns, & Lukito, 2011), few have focused on young children (Dennis et al., 2016; Mononen et al., 2014). Reviews concluded that interventions that applied explicit teaching, with sequenced instruction in some order—often from easy to difficult—and with a clear focus on subject matter, lead to improved mathematical learning outcomes. Using the concrete-representational-abstract sequence in teaching has also been found to be effective (Kroesbergen & Van Luit, 2003). Several of these intervention programs were conducted successfully with small groups of children (Bryant, Bryant, Gersten, Scammacca, & Chavez, 2008; Mononen & Aunio, 2014). Effective intervention programs have often been implemented as supplementary instruction through which children participate in small group tutoring that functions synergistically with classroom instruction (Powell & Fuchs, 2015).

Several recent supplementary programs for very young, at-risk students, using effective instructional features, have applied rigorous experimental designs. For example, Clarke et al. (2016) developed a 50-lesson (Tier 2) kindergarten math intervention that aims to support children's development of early numeracy. They tested its effects in a randomized controlled trial (RCT) that assigned 66 kindergarten classrooms to treatment and to control conditions randomly. Results showed that the intervention was beneficial for children at risk for mathematical learning difficulties, but it did not fully eliminate the gap between at-risk and average-achieving children (see Clarke et al., 2016). Dyson et al. (2011) designed an early numeracy intervention for low-performing kindergarteners who were at risk for mathematical learning difficulties and investigated the design's efficacy, with children randomly assigned to one of two groups: intervention condition or business-as-usual. Their intervention was carried out in small groups and comprised three 30-minute sessions per week for eight weeks. Children at risk for mathematical learning difficulties in the early numeracy intervention group made larger gains than control-group children, and the intervention effects held six weeks after the intervention had been carried out. Jordan, Glutting,

Dyson, Hassinger-Das, and Irwin (2012) conducted a randomized, controlled study, comprising an early numeracy intervention with first-graders at risk for mathematical learning difficulties and found that children who received the early numeracy intervention performed better than controls and that many of the effects held eight weeks after the intervention ended. To conclude, these intervention programs show positive effects right after the intervention, but also in delayed measurement, demonstrating sustainable learning effects as a result of early numeracy interventions (Barnes et al., 2016; Clarke et al., 2016; Dyson et al., 2011; Jordan et al., 2012). Although evidence of success in early numeracy programs exists in the United States and Europe, scant evidence exists from other parts of the world, including low income countries.

## 1.3. Early Numeracy, Executive Functions, and Language Skills

As proposed by LeFevre et al. (2010) and Sowinski et al. (2015) some quantitative, linguistic (language), and working memory (executive functions) pathways make unique contributions to mathematical development. Executive function (EF) skills have been found to be related to mathematical performance throughout childhood and adolescence (Cragg, Keeble, Richardson, Roome, & Gilmore, 2017). Although EF is conceptualized as a multidimensional construct comprising inhibition, updating, and cognitive flexibility (Miyake et al., 2000), extant research suggests that these cognitive processes are not separable in younger children (e.g., Wiebe, Espy, & Charak, 2008), whose EF skills have consistently been related to early numeracy skills in general (Purpura, Schmitt, & Ganley, 2017), as well as to different sub-skills, such as arithmetic (Simmons, Willis, & Adams, 2012), counting (Passolunghi & Lanfranchi, 2012), and numerical relations (Kolkman, Kroesbergen, & Leseman, 2013). Furthermore, longitudinal studies have shown an association between children's EF and growth in mathematical skills. However, these studies only examined overall math development (Lee & Bull, 2016; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017), while longitudinal studies on different math sub-skills are lacking.

In addition to EF, language skills have been deemed crucial for early numeracy skills (LeFevre et al., 2010; Toll & Van Luit, 2014; Zhang, 2016). Research has shown that early language skills are related to both existing early numeracy performance and predictive of later mathematical performance (Hooper et al., 2010). Understanding receptive language (i.e., listening comprehension) is one of the early-developing literacy skills (Austin, Blevins-Knabe, Ota, Rowe, & Lindauer, 2011), although it has not received the same attention as vocabulary knowledge in relation to early numeracy learning (Purpura, Napoli, & King, 2019). Durand, Hulme, Larkin, and Snowling (2005) found significant correlations between listening comprehension and basic arithmetic skills in children ages 7–10, while Chow and Ekholm (2019) found similar results concerning receptive syntax and basic arithmetic and word-problem-solving skills. Taken together, previous studies have demonstrated that individual factors, such as, EF and language skills are related to early numeracy learning. However longitudinal studies have mostly related these factors to overall math development and not to growth in different early numeracy sub-skills. Furthermore, previous early numeracy interventions have not often controlled for these individual factors, nor measured different early numeracy skills before intervention, immediately, and delayed after intervention.

## 1.4. School Context in South Africa

In South Africa, schools can choose their language of instruction, although the national Department of Basic Education (DBE) recommends that children be taught in their home language until

third grade. In a nation with 11 official languages, schools should provide curricular content in these languages. Increasingly, more parents in South Africa select schools with English as their instructional language, because of the social capital that they believe it can bring. However, reports on literacy learning (NEEDU, 2013, 2014) indicate learning and teaching difficulties were encountered in classrooms in which the instructional language is mixed. Studies from the US show that English language learners (ELLs) in kindergarten, especially those from low-income families, fall behind their native speakers in early language and numeracy learning (e.g. Hoff, 2006). Moreover, the achievement gap between ELLs and children with English as their language at home continues to exist in mathematics throughout students' school careers (Rouse, Brooks-Gunn, & McLanahan, 2005). Evidence also indicates that ELL status and low language performance are linked to some, but not all, mathematical skills. Extant studies on mathematics performance differences between native English speakers and ELLs (e.g. Chang, Singh, & Filer, 2009) show that ELL children with low language skills perform more poorly than their higher-ability peers on mathematics word problems, but these differences did not extend to general nonverbal calculation skills. In addition, McLeod, Harrison, Whiteford, and Walker (2015) found that it was not language status, but rather children's overall language competence (regardless of whether they spoke only English or were multilingual) at ages 4 and 5 that made a difference in their educational outcomes at school (see also Kleemans, Segers, & Verhoeven, 2011). As ELL status is a potential risk for early numeracy learning also in South African education context, it was important to control ELL status when analyzing the effects of the intervention program.

In first grade, the South African Revised National Curriculum Statement (RNCS) for mathematics suggests the weighting of the teaching and includes the following areas of learning: numbers, operations and relationships (65%); patterns functions and algebra (10%); space and shape (11%); measurement (9%) and, data handling (5%) (South Africa. Department of Basic Education, 2011). 27.5 h per week is the time allotted for grade 1 learners to be in a class, with 4.5 of those hours spent on mathematics to being in a lesson. Teachers make use of mathematics workbooks, supplied by public education authorities, as well as commercial materials purchased by the school with funding from the provincial education department or from parents in the private schools.

### 1.5. The Present Study

Evidence-based intervention programs that impact children's learning are one option for confronting a negative developmental prognosis (e.g., Barnes et al., 2016; Clarke et al., 2016). As such, this study has the potential to contribute to extant research on effective mathematics instruction for children at risk for mathematical learning difficulties by examining an intervention program with an emphasis on early numeracy content and effective instructional design and delivery principles in an less investigated educational context, such as in South Africa. Previous early numeracy interventions have not controlled for language skills and executive functions, nor measured different early numeracy skills before intervention, immediately and delayed after intervention. As for instance Bryant et al. (2011, 2019) have used only early numeracy measures pre and immediately after intervention, although exceptions exist (Dyson et al., 2011; Jordan et al., 2012). Toll and Van Luit (2012) controlled for working memory, but otherwise, neither language skills, nor executive functions have seldom been controlled for in early numeracy interventions. The relevance of exposure to and the length of enhanced early childhood education on children's academic learning has been shown in previous studies (Domitrovich et al., 2013), but it has not been controlled in short term interventions. Thus, to control for possible confound-

ing effects from individual differences in factors that are influential for early numeracy skills, we included language skills and cognitive measures in the present intervention study. As a proxy for cognitive skills, we measured executive functions (Eriksen & Eriksen, 1974; Roebers & Kauer, 2009). To obtain a general picture of children's language performance, we measured their listening comprehension skills (Ragpot & Brink, 2016), because the children had not yet learned how to read. In addition, we collected information from teachers on whether each child was an English as a (second) language learner and whether the child had attended kindergarten (a measure for prior exposure to instruction). Furthermore, children's age and gender were included as covariates in the analyses. Gender needs to be considered as boys and girls have been found benefiting differently from early childhood education learning possibilities (Anders et al., 2012; Early et al., 2010). We have designed, based on previous review studies (Dennis et al., 2016; Mononen et al., 2014), an intervention program to support early numeracy learning for children at risk for mathematical learning difficulties, and used it in this study.

The aim of this study was to test the efficacy of an early numeracy intervention for first graders at risk for developing mathematics learning difficulties. We used a quasi-experimental design with intervention and control groups and pre-, post- and delayed posttest design. First, we divided children into low (at risk for mathematical learning difficulties) and average performing groups, based on their performance in an early numeracy test at the beginning of the school year. Second, the low performing children were further divided into an intervention group and low-control group while the average performing children formed the average-control group. We targeted multifactorial early numeracy, including numerical relational- and counting skills, as well as arithmetical word problems, instead of a unitary early numeracy factor often used in intervention studies. In addition, we investigated how language skills and executive function skills predict the level and development of early numeracy skills. We controlled for age, gender, home language, and prior educational opportunities in all analyses. We worked with the following research questions and hypotheses:

1 How does the intervention group differ in the development of early numeracy skills from pre- to delayed posttest, compared with the low- and average-control groups?

Based on previous studies, with similar intervention features, we expected the intervention group to develop more in early numeracy skills, compared to the low-control group (Hypothesis, H1) and show similar growth compared with the average-control group (H2).

2 How can executive functions and language skills explain variance in the level and the development of early numeracy skills?

We expected executive functions and language skills to explain individual differences in the early numeracy skills pretest scores (H3) and growth in early numeracy skills (H4).

## 2. Method

### 2.1. Participants

This study is part of a research project that investigates early numeracy learning and evidence-based pedagogical support in South African schools, with 267 children (132 girls and 135 boys) participating in this intervention study. The children's mean age was 81.27 months (6 years 9 months) ( $SD = 5.65$  months) at pretest.

The study was conducted in schools using English as the instruction medium in the greater Johannesburg area of the Gauteng Province. The sample is a convenience sample from one large South African province. Four public schools (207 children) and three private schools (60 children), some with a population of low income-, and some of middle-income households, were included. The children in this study were first-graders at the beginning of their school year. Teachers were asked to report the children's home language, as well as their possible kindergarten attendance. The different home languages (HLs) reported among the 267 children were Setswana ( $n = 86$ ), isiXhosa ( $n = 9$ ), isiZulu ( $n = 45$ ), Sesotho ( $n = 17$ ), English ( $n = 79$ ), Afrikaans ( $n = 5$ ), and several others ( $n = 26$ ), some of which were children from immigrant families. Taken together, 188 of the children were ELLs. In this sample, 191 (71.5%) of the children had attended kindergarten. We set the cut-off point for at risk for mathematical learning difficulties in the early numeracy test (see Measures section for description of the test) at the 30th percentile (Geary, 2013; Zhang et al., 2020) to ensure that we 'catch' all those children who may potentially have problems in mathematical learning at school, based on their low early numeracy performance at the outset of their school career. The at-risk children were divided into an intervention group, consisting of 40 children (19 girls, 21 boys), and a low-control group, comprising 32 children (10 girls, 22 boys). All children above the 30th percentile formed the average-control group, which contained 195 children (103 girls, 92 boys). The seven participating schools had previously collaborated with the university in development programs. Four schools were in the control group, having volunteered to assess children's skills, but not for any intervention. Intervention groups were formed in three schools (two public and one private), which volunteered to participate as intervention schools and had university graduate students assist with the work (three groups in one public school, two groups in another public school, and one group in the last (private) school). Each group comprised four to six children.

## 2.2. Measures

### 2.2.1. Early numeracy

Early numeracy skills were assessed using an English version of the originally Finnish early numeracy test (Aunio, Mononen, Ragpot, & Törmänen, 2016). The test's aim is to identify children who are at risk for mathematical learning difficulties and who are in need of extra educational support. The test is a paper-and-pencil test that can be administered with groups of children. The test includes tasks (see Electronic Supplementary Material A for sample items) covering numerical relational skills (comparison concepts with quantities and comparison of numbers,  $n = 12$ ), counting skills (number sequences with forward and backward direction and with missing numbers, as well as number word-quantity-number symbol relations,  $n = 27$ ), and arithmetical word problems (verbal addition and subtraction problems,  $n = 4$ ). One point is scored for each correct answer and zero for wrong answers, with 43 the highest possible score.

### 2.2.2. Listening comprehension

Listening comprehension skills were measured using text from a children's story, Gogo's Dog (Hartmann & Rankin, 2013), with a listening comprehension scale (Ragpot & Brink, 2016), based on the Shell-K listening comprehension protocol (originally developed by Snow, Burns, & Griffin, 1998). The test comprises one story (fiction) with 15 questions, ranging in difficulty from basic factual questions to questions that require the child to infer answers from the text. The child responded orally, and the research assistant filled in the answer sheet. One point was scored for a correct answer and zero for a wrong answer, with 15 the highest possible score.

### 2.2.3. Executive function skills

The EF measurement that was used in the present study was a child-appropriate adaptation of the Eriksen flanker test (Eriksen & Eriksen, 1974; Roebers & Kauer, 2009), operated with ePrime software. The test was administered using laptop computers with a separate touch pad with white and black buttons. The target consisted of a red fish presented over a blue background. Children were instructed and trained to respond as quickly as possible, based on whether the fish was pointing to the left or right side, by pressing on the corresponding button on the touch pad. During the task activity, children were confronted with four different conditions: For the congruent trials, there were two fish on each side pointing in the same direction as the target fish in the centre. For the incongruent trials, the flanking fish pointed in the opposite direction. For the neutral trials, there were two starfish on each side (to be ignored), and for the alone trials, the target fish appeared alone. All trials were separated by a central fixation cross and presented in random order. Interstimuli intervals varied between 800 and 1400 msec. This program records the children's reaction times and accuracy of their answers per item. We used a composite score of accuracy (possible range 0–96) in the analyses.

### 2.2.4. Background variables

Background information on each child was requested from the teachers in a short questionnaire, which was administered at the beginning of the study. We collected information on children's age, gender, kindergarten attendance (yes/no), and home languages (i.e., ELL status). Correlations and descriptive statistics of all study variables can be found in Table 1 and descriptive statistics by study condition can be found in Table 2.

## 2.3. Early Numeracy Intervention Material

Based on previous studies, we designed an intervention program to support early numeracy learning among children with low early numeracy performance, i.e., children at risk for mathematical learning difficulties. The goal of our intervention material is to prevent mathematical learning difficulties and aims to avoid later learning problems in young children who may be at risk for such learning difficulties, due to low performance in early numeracy (Coding et al., 2011; Dennis et al., 2016; Mononen et al., 2014). The intervention material was designed to be used with a small group of children (three to eight per group) (Bryant et al., 2008). It is a supplementary intervention program during which children follow average mathematics lessons, and in addition to that, receive extra educational support in early numeracy skills. The material is designed to practice essential numerical relational and counting skills (number range: 0–10) (Aunio & Räsänen, 2015) (see Electronic Supplementary Material B for a description of the intervention material). These skills are important for early numeracy learning (Sarama & Clements, 2009). In addition, skills practiced during our intervention program also included understanding of mathematics-related language terms, such as "more", "less" "many" "fewer" called also as quantitative language by Purpura and Reid (2016).

In the program, explicit teaching is one of the main guidelines, along with several ways to practice the skills in focus (Mononen et al., 2014). In line with these recommendations, each lesson of this program comprises a teacher-guided activity on which to model a newly introduced concept and strategy, as well as guided- and peer activities (e.g., hands-on activities with manipulatives, or card and board games based on the current topic). At the end of the lesson, a short, paper-and-pencil, individual activity is assigned. Another general feature is that numeracy ideas are represented by sequencing the concrete, representational, and abstract levels, thereby giving meaning to abstract concepts through visual representations (e.g., cubes, bundles of sticks, and dot cards structured

**Table 1**

Means and standard deviations of and correlations among the study variables.

Variable	<i>M</i>	<i>SD</i>	1	2	3	4	5	6	7	8	9	10	11	12
1. Numerical relational skills T1 (max 12)	6.64	2.86	—											
2. Numerical relational skills T2 (max 12)	7.83	2.63	.69	—										
3. Numerical relational skills T3 (max 12)	8.60	2.48	.64	.62	—									
4. Counting skills T1 (max 27)	16.82	6.82	.69	.61	.62	—								
5. Counting skills T2 (max 27)	20.41	5.87	.51	.64	.56	.66	—							
6. Counting skills T3 (max 27)	21.60	5.58	.49	.46	.64	.62	.64	—						
7. Executive functions (max 96)	71.73	16.20	.47	.36	.46	.41	.33	.42	—					
8. Listening comprehension (max 15)	9.70	2.64	.51	.42	.39	.46	.36	.37	.30	—				
9. Age	81.27	5.65	.22	.20	.09	.18	.08	.08	.19	.08	—			
10. Gender (0 = girl, 1 = boy)	0.51	0.50	—.06	−.05	−.10	−.18	−.13	−.13	.03	−.09	.07	—		
11. ELL (0 = no, 1 = yes)	0.70	0.46	−.40	−.35	−.29	−.33	−.33	−.28	−.23	−.37	−.10	.05	—	
12. Kindergarten attendance (0 = no, 1 = yes)	0.72	0.45	.45	.35	.40	.53	.39	.36	.31	.29	.22	−.13	−.21	—
Cronbach's alpha			.75	.74	.73	.92	.90	.89	.87	.70				

Note: *N* = 267. Correlations equal to or greater than .12 were significant at *p* < .05; correlations equal to or greater than .16 were significant at *p* < .01; correlations equal to or greater than .20 were significant at *p* < .001. T = timepoint; ELL = English language learners.

**Table 2**

Descriptive statistics of the variables under study by condition.

	intervention group ( <i>N</i> =40)		low-control group ( <i>N</i> =32)		average-control group ( <i>N</i> =195)					
Variable	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>F</i>	<i>p</i>	$\eta_p^2$	
Numerical relational skills T1	4.05 <sup>b</sup>	1.58	4.25 <sup>b</sup>	1.69	7.56	2.65	52.54	<.001	.28	
Numerical relational skills T2	5.78 <sup>a</sup>	2.29	5.88 <sup>a</sup>	1.98	8.57	2.40	36.55	<.001	.22	
Numerical relational skills T3	7.08	2.10	5.75	2.12	9.36	2.12	46.94	<.001	.28	
Counting skills T1	8.53 <sup>b</sup>	4.10	9.22 <sup>b</sup>	3.63	19.77	5.08	137.08	<.001	.51	
Counting skills T2	16.43 <sup>b</sup>	6.70	16.19 <sup>b</sup>	5.94	21.92	4.90	29.03	<.001	.18	
Counting skills T3	16.82 <sup>b</sup>	6.39	16.86 <sup>b</sup>	6.36	23.33	4.11	44.28	<.001	.27	
Executive functions	62.77 <sup>a</sup>	13.13	58.77 <sup>a</sup>	13.60	75.63	15.39	24.98	<.001	.16	
Listening comprehension	7.40	2.72	8.94	2.44	10.30	2.35	25.69	<.001	.16	
Age	79.58 <sup>a</sup>	6.08	80.88 <sup>a</sup>	5.71	81.68 <sup>a</sup>	5.50	2.42	=.091	.02	
Girls	%		%		%					
English language learners	47		31		53					
Kindergarten attendance	75		97		65					
	28		47		85					

Note: Group means within a row sharing the same superscript are not significantly different at the *p* < .05 level with <sup>a</sup>Bonferroni correction/<sup>b</sup>Games-Howell post hoc test due to unequal variances.

in tens and hundreds) (Kroesbergen & Van Luit, 2003). The teacher manual includes 15 lesson plans, with each lesson lasting 35–45 min. Intervention sessions took place three times per week for five weeks. The lesson plans included specific instructions for teachers. The manipulatives are made of low-cost, everyday materials found in every classroom, combined with printable materials (e.g., dot cards) included in the manual.

#### 2.4. Procedure

Permission to conduct research in the schools was obtained from the local, provincial Gauteng Department of Education, various school-management teams, and governing bodies. Consent letters were then sent to families to inform parents about the research and obtain their permission for their children to participate. A native speaker of both Finnish and English translated the early numeracy scale into English. The research team checked the translation's accuracy. All tests were administered in English during the regular school day in children's own classroom. The listening comprehension test was administered individually in a separate venue, away from the classroom. The EF tasks were completed individually, using laptop computers with response buttons. Trained research assistants and one of the authors administered the tests and scored them. Measurements were made before the intervention (Time 1), immediately after the intervention (Time 2), and three months after the intervention had ended (Time 3).

A native speaker in both languages, with a master's degree in education, translated the intervention material from Finnish to English, and the Finnish and South African research team checked

the translation by back-translating. Intervention materials were given to teachers as a ready-to-use intervention kit. The research team trained five special education teachers and educational psychology interns, working at the schools, on how to use the material. A full-day workshop was conducted before the intervention started. During this time, the whole project was discussed. Groups were assigned, and a brief overview of the 15 lessons was provided. After that, three meetings were held during the intervention, in which five lessons were discussed thoroughly during each session. These sessions lasted about two hours each, and one member of the research team visited intervention teachers bi-weekly for informal discussions.

#### 2.5. Fidelity

To secure fidelity teachers made entries in logbooks during the intervention period. They were asked to report on the tasks that they had completed and the children's participation during each session. Further information was recorded on a seven-point scale and it focused on the task difficulty level for the children, how interested the children were in the tasks, and how well the children were able to concentrate on the tasks. After the intervention period, a whole-day debriefing and feedback session was held with teachers and researchers, in which the qualitative input from the logbooks added rich descriptions of how the tasks could be adapted for the South African classroom. The intervention program itself was conducted with small groups of children (four to six per group) and led by special-education teachers or student interns. There were three sessions per week, each lasting 45 min. Most of the chil-

dren attended all intervention sessions, with four students missing one session due to illness or absence from school on that day. The children in the intervention group were fetched from the regular classroom for the program sessions, while the children in the control groups would continue with other class activities, mainly doing homework, or engaging in art or physical exercise lessons. We did not design activities for them. Due to financial restrictions, and not foreseen in the initial planning, it was not possible to offer the control group children early numeracy intervention sessions after the original intervention study had been completed.

Teachers in the intervention group reported that they conducted all 15 sessions as planned. Each session was about 45 min long, and no problems were reported. At the beginning of the intervention, one teacher was a bit reticent about whether the program would work. However, after researchers had met with her and answered her questions about the benefits of intervention, she was willing to continue. Teachers reported that at all schools the children eagerly requested to be part of the intervention group.

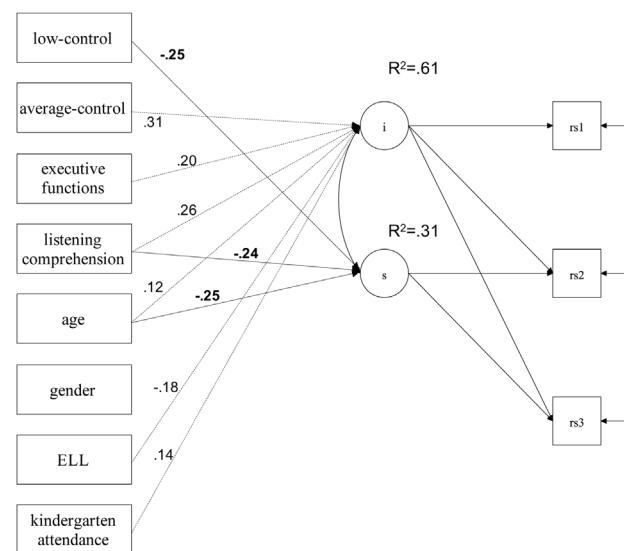
## 2.6. Data Analysis

Separate composite scores for all three timepoints were calculated for the three early numeracy sub-skills (Table 1). Preliminary analyses indicated poor test-retest reliability for the arithmetical word problems, which led to our discarding of this sub-skill from the main analyses. Latent growth curve modeling (LGCM) was used to analyze change in early numeracy scores from pre- to delayed test. Separate growth models were estimated for numerical relational and counting skills. The intervention group was set as the reference group and dummy-coded low-control and average-control groups, EF, listening comprehension, kindergarten attendance, age, gender, and home language were added to the models as covariates. The intervention effect size was calculated by dividing the difference between the estimated means of the intervention and low-control/average-control groups at the delayed posttest (determined from the coefficient for the slope difference and length of study) by the baseline standard deviation (Feingold, 2009).

## 3. Results

### 3.1. Numerical Relational Skills

The modeling started by fitting a linear LGCM to the numerical relational skills data without any covariates ( $M_{1\text{relational}}$ ). The model fitted the data well (Table 3), and the slope mean was significant ( $M = 0.99, p < .001$ ), indicating positive growth in children's numerical relational skills from pre- to delayed posttest. The slope variance (0.11) was not significant ( $p = .74$ ). The intercept mean ( $M = 6.71$ ) and variance (5.81) and the correlation between the intercept and slope ( $r = -.64$ ) were significant ( $p < .001$ ). The negative correlation between the intercept and the slope indicated that those with lower pretest scores developed more in their relational skills. Next, we included the dummy-coded variables for the low-control and average-control groups as covariates in the model ( $M_{2\text{relational}}$ ). As expected, a significant effect was found from the average-control group on the intercept ( $\beta = .62, p < .001$ ), indicating that children in the average-control group had higher numerical relational skills at pretest compared with the intervention group. The low-control group did not differ in numerical relational skills at pretest from the intervention group ( $\beta = .05, p = .53$ ). However, a significant negative effect existed from both the average-control ( $\beta = -.45, p < .05$ ) and low-control ( $\beta = -.39, p < .05$ ) groups on the slope, indicating that the intervention group developed more in numerical relational skills from pre- to delayed posttest compared with both



**Fig. 1.** Predicting the intercept and slope in numerical relational skills from pre- to delayed posttest. ELL = English language learners.



**Fig. 2.** The development of children's numerical relational skills from pre- to delayed posttest as a function of group membership when controlling for executive functions, language skills, age, English language learners, kindergarten attendance and gender.

control groups. After this, the other covariates were included in the model one at a time (models:  $M_{3\text{relational}} - M_{8\text{relational}}$ ), and as can be seen in Table 3, the model fit was excellent for all models.

Higher pretest scores (intercept) were related to being in the average-control group ( $\beta = .31, p < .001$ ), higher EF ( $\beta = .20, p < .001$ ), higher language skills (listening comprehension) ( $\beta = .26, p < .001$ ), higher age ( $\beta = .12, p < .05$ ), English as a first language ( $\beta = -.18, p < .001$ ), and kindergarten attendance ( $\beta = .14, p < .05$ ) (Fig. 1). Children in the intervention group (compared with the low-control group) ( $\beta = -.25, p < .1, \text{ES} = .41$ ), younger children ( $\beta = -.25, p < .05$ ), and children with lower language (listening comprehension) skills at pretest ( $\beta = -.24, p < .1$ ), developed more in numerical relational skills from pre- to delayed posttest. Interestingly, the intervention group continued to improve more compared with the low-control group after the intervention ended (Fig. 2). To find out whether the intervention effect was present in the delayed posttest, we re-specified the LGCM so that the delayed posttest was set as the intercept. The intervention effect was visible in the delayed posttest as the intervention group outperformed the low-control group ( $\beta = -.16, p < .05$ ). The difference between the intervention and average-control group was still significant at the delayed posttest in favor of the average control group ( $\beta = .23, p < .01$ ). In sum, H1, H2, and H3 were confirmed, while H4 was rejected concerning numerical relational skills.

**Table 3**

Model fit of the latent growth curve models for numerical relational skills.

Model	$\chi^2 (df)$	p	CFI	TLI	RMSEA
M1 <sub>NRS</sub> NRS (linear growth)	3.292 (1)	.07	.993	.979	.093
M2 <sub>NRS</sub> +group	7.855 (3)	.05	.989	.967	.078
M3 <sub>NRS</sub> +group + EF	10.357 (4)	.03	.986	.958	.078
M4 <sub>NRS</sub> +group + EF + LC	10.435 (5)	.06	.989	.966	.065
M5 <sub>NRS</sub> +group + EF + LC + age	12.608 (6)	.05	.986	.959	.065
M6 <sub>NRS</sub> +group + EF + LC + age + ELL	13.166 (7)	.07	.987	.962	.059
M7 <sub>NRS</sub> +group + EF + LC + age + ELL + KA	14.670 (8)	.06	.987	.960	.057
M8 <sub>NRS</sub> +group + EF + LC + age + ELL + KA + gender	14.847 (9)	.09	.988	.965	.050

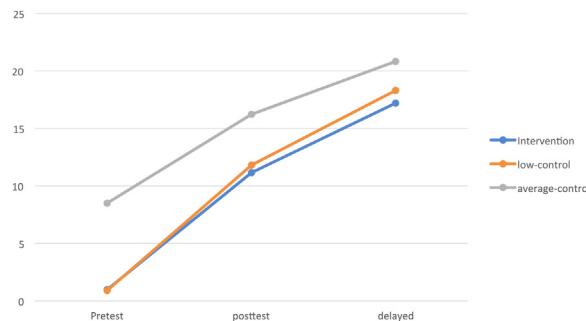
Note: NRS = numerical relational skills; group = dummy-coded low-control and average-control variables; EF = executive functions; LC = listening comprehension; ELL = English language learners; KA = kindergarten attendance.

**Table 4**

Model fit of the latent growth curve models for counting skills.

Model	$\chi^2 (df)$	p	CFI	TLI	RMSEA
M1 <sub>CS</sub> CS (linear)	19.454 (1)	.000	.941	.822	.263
M2 <sub>CS</sub> CS (logarithmic)	4.763 (1)	.03	.988	.964	.12
M3 <sub>CS</sub> +group	24.271 (3)	.001	.958	.874	.163
M4 <sub>CS</sub> +group + EF	21.042 (4)	.0003	.965	.896	.129
M5 <sub>CS</sub> +group + EF + LC	21.669 (5)	.0006	.967	.901	.114
M6 <sub>CS</sub> +group + EF + LC + age	21.887 (6)	.0013	.969	.906	.102
M7 <sub>CS</sub> +group + EF + LC + age + ELL	23.139 (7)	.0016	.969	.906	.095
M8 <sub>CS</sub> +group + EF + LC + age + ELL + KA	25.181 (8)	.0014	.968	.903	.091
M9 <sub>CS</sub> +group + EF + LC + age + ELL + KA + gender	25.387 (9)	.0026	.969	.908	.084

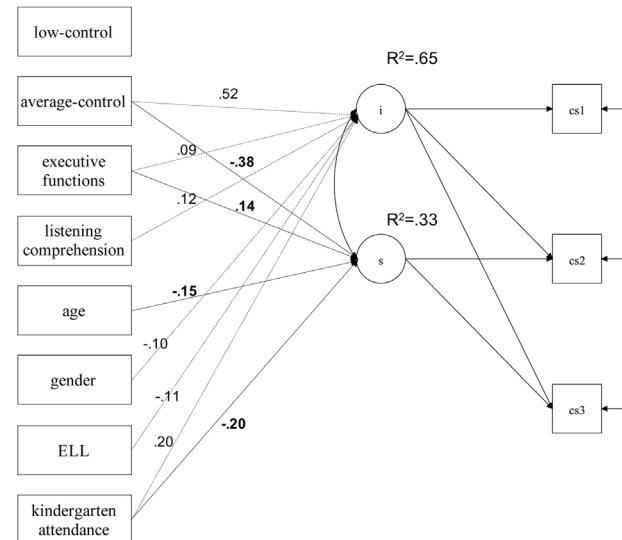
Note: CS = counting skills; group = dummy-coded low-control and average-control variables; EF = executive functions; LC = listening comprehension; ELL = English language learners; KA = kindergarten attendance.



**Fig. 3.** The development of children's counting skills from pre- to delayed posttest as a function of group membership when controlling for executive functions, language skills, age, English language learners, kindergarten attendance and gender.

### 3.2. Counting Skills

First, a linear LGCM was fitted to the counting-skills data, but this model ( $M1_{counting}$ ) did not fit the data that well. An examination of the descriptive statistics indicated that the counting skills at T3 showed a ceiling effect, especially among the average-control group's children. Consequently, a logarithmic LGCM was fitted to the data, where the factor loadings for the slope factor was set as 0.69 and 1.1 respectively. This model ( $M2_{counting}$ ) showed good model fit (Table 4), with a significant slope mean ( $M = 4.42, p < .001$ ), indicating that overall, the students' counting skills improved from pre- to delayed posttest (Fig. 3). The slope variance (0.96) was not significant ( $p = .88$ ). The intercept mean ( $M = 17.01$ ), variance (29.77) and the correlation between the intercept and slope ( $r = -.60$ ) were significant ( $p < .001$ ). The negative correlation between the intercept and the slope indicated that those with lower pretest scores developed more in their counting skills. Next, we added the control groups as dummy variables in the model and, as expected, the average-control group had higher counting-skills scores at pretest ( $\beta = .74, p < .001$ ). The intervention group developed more in counting skills from pre- to delayed posttest, compared with the average-control group ( $\beta = -.50, p < .001$ ), but no differences



**Fig. 4.** Predicting the intercept and slope in counting skills from pre- to delayed posttest. ELL = English language learners.

existed in development between the intervention group and the low-control group ( $M3_{counting}$ ). Next, we added the other covariates to the growth model one at a time, and the model fit of these models was reasonable. The full model with all the covariates fitted the data adequately ( $M9_{counting}$ ). Higher pretest scores (intercept) were related to being in the average-control group ( $\beta = .52, p < .001$ ), higher EF ( $\beta = .09, p < .1$ ), higher language skills (listening comprehension) ( $\beta = .12, p < .05$ ), English as a first language ( $\beta = -.11, p < .05$ ), being a girl ( $\beta = -.10, p < .05$ ), and attending kindergarten ( $\beta = .20, p < .001$ ). Children in the intervention group (compared with the average-control group) ( $\beta = -.38, p < .001$ ), younger children ( $\beta = -.15, p < .05$ ), children with higher EF ( $\beta = .14, p < .1$ ), and children who did not attend kindergarten ( $\beta = -.20, p < .05$ ) developed more in counting skills from pre- to delayed posttest (Fig. 4). In sum, H1

and H2 were rejected while H3 and H4 (for EF) were confirmed concerning counting skills.

#### 4. Discussion

This study's aim was to test an early numeracy intervention's efficacy for first graders at risk for developing mathematics learning difficulties in a sample of South African schools. The main result of our early numeracy intervention was that the intervention group improved more in numerical relational skills, when compared with an at-risk control-group of children. This effect remained statistically significant after controlling for other variables (language, executive functions, and kindergarten attendance). Moreover, the intervention effect on numerical relational skills was still present in the delayed measurement. A positive effect from education across condition was seen in children at risk for mathematical learning difficulties, as both at-risk groups (intervention and control) developed more in their counting skills, compared with the average-control group. Regarding the covariates, the results showed that instruction, overall, in the first school term worked well in supporting children who may be disadvantaged in that they may be younger children and do not yet have well developed listening comprehension skills, which they need for early numeracy development in a classroom context. Interestingly, this was not the case for executive functions, as EF continued to exert a positive effect on children's counting-skills development but did not predict relational skills development.

Hypothesis 1 was confirmed partly, because the intervention group developed more in numerical relational skills compared with the at-risk-control group, but not in counting skills. Compared with the average-control group, the intervention group developed more in counting skills and at the same pace in numerical relational skills, thereby partly confirming H2. However, this steeper growth in counting skills for the intervention group compared to the average-controls can probably be explained by the ceiling effect in the measure. Our research results in this study are in line with previous early numeracy intervention studies with children at risk for mathematical learning difficulties in the United States and Europe, showing that explicit instruction in small groups of children is effective (Bryant et al., 2008; Clarke et al., 2016; Dyson et al., 2011; Jordan et al., 2012; Toll & Van Luit, 2012, 2014). More precisely, interventions that incorporate systematic instructional design, which sequences tasks from easy to difficult, and task analysis, that is combined with teachers' explicit explanations of concepts and procedures support learning. Furthermore, small-group instruction works well in supporting learning of young children at risk for mathematical learning difficulties (Coding et al., 2011; Dennis et al., 2016; Kroesbergen & Van Luit, 2003; Mononen et al., 2014).

The relevance of a mathematical language on early numeracy learning has been emphasized recently (e.g., Purpura et al., 2019). The numerical relational skills practiced and measured in our study are similar to tasks measuring mathematical language (Purpura & Reid, 2016; Purpura et al., 2019). We found long-lasting significant increases in numerical relational skills. During our program numerical relational skills were practiced, for instance, with tasks in which teacher and children are in a group: A picture of an adult and a child is put on the whiteboard, table, or the floor. Each child and adult put their object under the picture that represents the group to which they belong. The teacher asks: How many children? How many adults? Are there more adults or children? Which are fewer? How many more children are there than adults? This extra practice is especially important for children who have different home languages than the one used in school (Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010); this is common in South

African schools and it was the case in our sample as well. Our results endorse the argument that rich use of mathematical language is beneficial for at-risk children's learning (Hassinger-Das, Jordan, & Dyson, 2015; Purpura et al., 2019). H3 was confirmed, as both language and executive function skills were related positively to pretest scores, both in numerical relational skills, and in counting skills. These results are in line with the frameworks of LeFevre et al. (2010) and Sowinski et al. (2015), which emphasize the importance of language and executive functions for mathematical learning, and with extant literature in general (e.g., Schmitt et al., 2017; Zhang, 2016). Our results also are in line with Cragg et al. (2017), who found evidence in their study, of a hierarchical framework for mathematics learning, in which domain-general executive function skills, particularly working memory, support domain-specific mathematical processes that underpin overall mathematics achievement. In their use of several cross-sectional data sets, they also reported additional evidence that working memory directly contributes to mathematical achievement (e.g., Morgan et al., 2019). H4 was only partially confirmed, as executive functions only explained growth in counting, but not in numerical relational skills. Our results that executive-function skills explained growth in counting skills is in line with previous interventions (Toll & Van Luit, 2012) and longitudinal studies (Lee & Bull, 2016; Schmitt et al., 2017) that have shown that executive functions are related to growth in mathematical skills in general. This is understandable, as EF processes are important in mathematical problem-solving skills in general, and in counting skills in particular (Lee & Bull, 2016). However, it seems that growth in numerical relational skills is not supported by more domain general cognitive skills (e.g., EF). One explanation could be that previous studies have found a weaker relation between EF and easier math tasks (Geary, 2011), and tasks that require fewer steps to solve successfully (Lee & Bull, 2016). Furthermore, Prager, Sera, and Carlson, (2016) found that 4-year-olds performed well on a magnitude comparison task despite varying EF demands, suggesting that EF skills might not be crucial in this type of task, which taps into basic number processing skills. Contrary to Hooper et al. (2010), language skills were not related to growth in early numeracy skills in our study. This might be due to different operationalizations of language and early numeracy skills; we used receptive language and narrow early numeracy subskills, while Hooper et al. used expressive language and a broad math measure in their study. Furthermore, the timespan in their study was much longer compared to ours.

##### 4.1. Limitations and Recommendations for Further Studies

Although the early numeracy measure has demonstrated good psychometric properties in previous cross-sectional studies (Aunio et al., 2019); Lopez-Pedersen, Mononen, Korhonen, Aunio, & Melby-Lervåg, 2020) we were unable to investigate the intervention's efficacy on the arithmetic word-problem solving sub-skill, due to poor test-retest reliability. This probably was due to the rather low number of items measuring this sub-skill. Furthermore, the results indicate that the counting sub-skill probably suffered from ceiling effects, at least for the average-control group. All our assessments were conducted in English, which might have been a problem for some of the ELL children. Another potential factor resulting in "too positive" findings was the fact that the selection of schools was not random but based on volunteering teachers. The active teachers and schools were probably also active in general developing their school and individual teaching skills.

We used one measure of program implementation, teachers' logbooks, which included a count of the number of lessons completed and possible problems reported. Unfortunately, we were unable to record lessons by way of audio- or video recordings. Such recordings would have been valuable in addressing the fidelity

concern. In this study, the intervention materials could have been better tailored to fit schools' needs. Training in this study was typical of the professional development level that publishers of instructional curricula provide to district personnel (e.g. Agodini & Harris, 2010): one full day of training, followed by phone and email support. This is much less than what often is seen in tightly controlled efficacy studies (e.g., Fuchs et al., 2005). A recent study with 17 South African kindergarten teachers found that their knowledge of teaching core early numeracy skills was superficial (Venkat & Spaull, 2015). However, the intervention teachers in our study were all trained at master's level, so it is expected that they were more knowledgeable than the teachers in the Venkat and Spaull (2015) study.

Our intervention program included key components of effective instruction for children at risk for learning difficulties in mathematics: explicit teaching, with sequenced instruction in order of difficulty, with a clear focus on subject matter, and the use of the concrete-representational-abstract sequence (Coding et al., 2011; Dennis et al., 2016; Kroesbergen & Van Luit, 2003; Mononen et al., 2014). These have been demonstrated to be effective for ELL learners and children from low socioeconomic status home backgrounds (e.g., Cass, Cates, Smith, & Jackson, 2003; Gersten et al., 2009). LeFevre et al.'s (2010) pathways-to-numeracy approach valid, but needs to be tested outside of North America and Europe to understand the learning and workable support mechanisms for diverse educational contexts. The COVID-19 pandemic has shown that it is also highly relevant to study possibilities to provide educational support for children at risk for learning difficulties remotely. Research about this must begin right now.

## 5. Conclusion

Our study provided additional evidence in line with previous studies about the effects of an early numeracy intervention on low performing first graders; we measured early numeracy skills before, immediate and delayed after the intervention, we controlled for executive functions, language skills and previous kindergarten attendance. In addition, we operationalized early numeracy as a multidimensional construct and used latent growth curve modeling that allows for flexible modeling options and takes into account measurement error. Our intervention program included key components of effective instruction for children at risk for learning difficulties in mathematics: explicit teaching, with sequenced instruction in order (e.g., easy to difficult, a clear focus on subject matter, and the use of the concrete-representational-abstract sequence (Coding et al., 2011; Dennis et al., 2016; Kroesbergen & Van Luit, 2003; Mononen et al., 2014).

## CRediT authorship contribution statement

**Pirjo Aunio:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Writing - original draft, Writing - review & editing. **Johan Korhonen:** Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Lara Ragpot:** Investigation, Project administration, Resources, Writing - review & editing. **Minna Törmänen:** Investigation, Methodology, Writing - review & editing. **Elizabeth Henning:** Resources, Writing - review & editing.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.ecresq.2020.12.002>.

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