



# Effects of remedial numeracy instruction throughout kindergarten starting at different ages: Evidence from a large-scale longitudinal study



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## ABSTRACT

The aims of this study are to investigate the effects of remedial numeracy support throughout kindergarten, and to compare the effects of interventions from different lengths. Support occurred two times per week for either 1.5 (90 sessions: complete condition) or 0.5 school years (28 sessions: short condition). Below-average students were randomly assigned to complete intervention ( $N = 155$ ), short intervention ( $N = 105$ ), or control (systematically offered education-as-usual;  $N = 150$ ). Accounting for achievements at pretest, children who received one of the interventions outperformed the control children in early numeracy at post-test and follow-up, suggesting that children internalized the learned knowledge. Transfer effects on simple arithmetic were only found in the complete support group, whereas both interventions were effective for complex mathematics.

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## 1. Introduction

Early numeracy performance at four or five years of age has a far-reaching influence on learning mathematics (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004). In fact, early numeracy skills in kindergarten predict mathematics learning through to the end of sixth grade (Kavkler, Aubrey, Tancig, & Magajna, 2000), and can even predict mathematical competence in higher education (Siegler, 2009). Moreover, children who perform worse than their peers in basic quantitative knowledge during kindergarten tend to remain behind throughout their schooling (Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010). Thus, low early numeracy is an indicator of risk of long-term math learning disabilities (Toll, Van der Ven, Kroesbergen, & Van Luit, 2011); kindergartners and school beginners with inadequate early numeracy skills who have not yet begun to fail in school should therefore be supported during kindergarten years through preventive interventions (Dowker, 2005).

In the present study, we investigated the effects of a remedial early numeracy program especially designed for children at risk of mathematical learning difficulties, namely children scoring low on

a standardized early numeracy test. The goal was to refine and test two early numeracy program versions of different durations.

### 1.1. Low early numeracy as risk factor

Early numeracy can be defined as the general understanding of numbers (Gersten et al., 2012; Passolunghi & Lanfranchi, 2012), and can be divided into several skills, including (verbal) counting, knowing the number symbols, recognizing or discerning quantity patterns, comparing numerical magnitudes, and estimating quantities (e.g. Gersten, Jordan, & Flojo, 2005). The consequences of (low) early numeracy in preschoolers and kindergartners have been studied repeatedly (e.g. Jordan, Kaplan, Ramineni, & Locuniak, 2009). Most children instinctively develop the prerequisites for learning mathematics through informal learning in the home environment (e.g. Anders et al., 2011). The fact that this is not true for all young children leads to significant variations between individual's early numeracy levels in kindergarten classes (Aunio, Hautamäki, Sajaniemi, & Van Luit, 2009). Whereas most children have mastered a range of early numeracy skills by this point, others do not have a thorough command of numbers, their meaning, or their interrelations (Jordan et al., 2010). This causes some children to already trail behind in their early numeracy knowledge by the age of five years and, as a result, make the transition from kindergarten to first grade with an insufficient understanding of numbers and related skills such as counting, estimating, and reasoning.

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Research shows that those children with inadequate early numeracy skills are hardly capable of catching up with their peers, and are thus at risk of developing mathematical learning difficulties at a later stage (e.g. Stock, Desoete, & Roeyers, 2010). Therefore, adequate remedial support should be offered during kindergarten to meet the needs of this at-risk group.

### 1.2. (Remedial) intervention in early numeracy

There is ample evidence that early numeracy can be enhanced through structured intervention (e.g. Griffin, 2004; Slavin & Lake, 2008). Empirical evidence centers on long-term curricular interventions (Slavin & Lake, 2008) such as Building Blocks (Clements, Sarama, Spitler, Lange, & Wolfe, 2011) or Big Math for Little Kids (Greenes, Ginsburg, & Balfanz, 2004), but interventions offered over a predetermined time frame have also proven to be effective (e.g., Kaufmann, Delazer, Pohl, Semenza, & Dowker, 2005; Kaufmann, Handl, & Thöny, 2003; Krajewski, Nieding, & Schneider, 2008). Yet, the duration of these interventions varies enormous. Whereas the kindergarten program of Kaufmann et al. (2005) was offered for about 15 min, twice- or thrice-weekly for 20 weeks, resulting in a total intervention time of about 750 min, the total intervention time of other interventions lasted more than twice as long. For example, one program was offered for 1500 min (30 min, five times per week for 10 weeks; Krajewski et al., 2008) and another program lasted about 1800 min (25 min, twice-weekly for six months; Kaufmann et al., 2003). These variations influence the interpretations of the conclusions and, as a consequence, make it difficult to perform cross-study comparisons. For this reason, Slavin and Lake (2008) formulated, in their best-evidence synthesis, one inclusion criterion focusing on duration. This requirement, a minimum treatment duration of 12 weeks, was intended to focus their review on practical programs intended for use for the whole year rather than on brief investigations, since brief studies may not show the full effect. Moreover, they state that brief studies often advantage experimental groups that focus on a particular set of objectives during a limited time period while control groups spread that topic over a longer period. This was congruent to the conclusion drawn by Kroesbergen and Van Luit (2003), stating that the duration of early numeracy interventions correlated negatively with effect size due to the focus on a very small and specific domain of knowledge. Indeed, several studies show intervention effects on different domain-specific skills (e.g., Obersteiner, Reiss, & Ufer, 2013), despite the very short intervention time. Siegler and Ramani (2008), for example, found that playing linear board games in four 15-min sessions (60 min in total) over the course of two weeks positively improved students' numerical representations (Ramani & Siegler, 2008, 2011). Meanwhile, Whyte and Bull (2008) demonstrated how early numeracy in kindergarten was enhanced by four 25-min sessions (100 min in total) of number games with exercises in number comparison and counting. Other studies, with a longer time frame, have provided evidence that promoting counting strategies over the course of 16 weeks of three 20–30 min sessions (about 1200 min in total) can stimulate kindergartners' numeracy abilities (Fuchs et al., 2010), as can certain types of early abstract thought with an intervention duration varying from 900 upto 1800 min in total, dependent on the moment the children met the predetermined criterion (e.g., Pasnak et al., 2009). Prior to such a domain-specific intervention, the children score very low; after a short period of intervention, however, they have fully acquired the relevant knowledge and thus score quite high. Longer interventions, focusing on a broader domain of numeracy knowledge, cost more time, and therefore, in general, produce smaller effect sizes than those specific interventions (Kroesbergen & Van Luit, 2003).

Although there is ample evidence that supporting early numeracy is possible in several ways and with intervention lasting different durations, less information is available about the effects of interventions especially designed for kindergartners at risk of poor mathematics outcomes. Studies with older children show that different types of interventions led to improvements in the mathematical achievements of students experiencing arithmetical difficulties (for a review, see Baker, Gersten, & Lee, 2002; Kroesbergen & Van Luit, 2003). We identified no randomized control studies contrasting different intervention lengths throughout kindergarten within one design, but we did locate several randomized control trials assessing intervention efficacy for at-risk kindergartners. Also in this type of studies a rough classification can be made between interventions within a shorter time frame (comprising less than 1000 min in total) and long lasting interventions (which go beyond those 1000 min). Studies within this last category show that children from low-economic status families – classified as being at risk – made significant gains on early numeracy achievement, or accessing those skills, when made a target of remedial intervention for about 1500 min (20–30 min, twice- or thrice-weekly, 20 weeks; Baroody, Eiland, & Thompson, 2009) or 1440 min (30 min, thrice-weekly, 16 weeks; Fuchs et al., 2013). However, effectiveness was also found for shorter interventions which took only 720 min (24 sessions of 30 min; Dyson, Jordan, & Glutting, 2013; Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012) or merely 120 min with an adaptive game intervention (six 20-min sessions; Wilson, Dehaene, Dubois, & Fayol, 2009). In a limited number of studies, children were detected as being at risk based on their early numeracy abilities. The results of these studies demonstrated that it is possible to stimulate the development of early mathematical competence among young, poor arithmetic achievers both within a time frame of 780 intervention minutes (30 min, twice-weekly, 13 weeks; Van de Rijt & Van Luit, 1998) or a longer duration of 1440 min (30 min, thrice-weekly, six months; Van Luit & Schopman, 2000) or 1900 min (25 min, four times per week, 19 weeks; Bryant et al., 2011). Although above results may suggest that duration effects may be ignorable, the results of one study reveal that intervention is not always promising for children belonging to the weakest range, i.e. those scoring below the 25th percentile (Toll & Van Luit, 2012). One explanation for this non-significant result may lie in the duration of this intervention, which was only 480 min (16 sessions of 30 min). Therefore, duration will be manipulated in the present study in order to investigate whether longer-lasting support yield more positive effects than time-limited remediation.

The target group of the intervention in the present study is children with a score in the lowest 50 per cent range of a Dutch norm group for the Early Numeracy Test – Revised (ENT-R; Van Luit & Van de Rijt, 2009). This criterion was chosen because these children are at low-to-high risk of developing math difficulties. The intervention program used here, *The road to mathematics* (Van Luit & Toll, 2013), was especially designed for the support of low-performing children. The program contains an intensive form of over-rehearsal, small task-focused (sub-)goals, and clear materials; these process variables provide the foundation for instruction (Fuchs & Fuchs, 2006). There are two versions of *The road to mathematics* available: the complete version can be offered over the course of 1.5 school years (90 sessions of 30 min; 2700 min in total); the short version for 0.5 years (28 sessions of 20 min; 840 min in total). Distinction between these two versions is based on previous studies, confirming that the length of an early numeracy intervention matters (e.g. Schopman & Van Luit, 1999). On the one hand, the literature (e.g. Kroesbergen & Van Luit, 2003) shows the value of long-term training; on the other hand, long-term structural support requires increased staffing and

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