The effects of educational computer game on low-performing children’s early numeracy skills—An intervention study in a preschool setting

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The effects of educational computer game on low-performing children’s early numeracy skills—An intervention study in a preschool setting
Abstract

The aim of this study was to determine the effects of an educational computer game, Lola’s World, on low-performing children’s early numeracy skills. Four preschools with 33 children from families of low socioeconomic status ($M_{\text{age}} = 5.5$ years) took part in this study. Of the 33 children, 23 were split randomly into two groups: an intervention group playing a numeracy game (Lola’s World) and an active control group playing an early reading skills game (Lola’s ABC party). The remaining 10 children served as a passive control group. The intervention phase lasted three weeks, during which time the children played the games daily for about 15 minutes. The children’s numeracy skills were measured using the Early Numeracy Test. Those children ($n = 22$) who exhibited low numeracy (i.e. at risk for learning difficulties in math) were included in the analyses. The three groups did not differ in terms of parental educational levels or home languages. They were comparable in terms of nonverbal reasoning and the amount of time spent playing. The Lola’s World group improved its early numeracy performance from pretest to posttest. No between-group differences were found. The results are discussed in relation to providing game-based support for low-performing preschoolers.

Keywords: at risk for learning difficulties, computer-assisted instruction, digital learning, early numeracy, intervention, low performance
**Introduction**

Digital learning is highly emphasised in Western cultures, and demands to include digital learning as a part of regular early childhood and comprehensive education are strong (Kavanagh and O’Rourke 2016). Although a large number of commercial educational games (i.e. apps) are available for (pre)schools to use in mathematics learning, only some appear to be research-based, and we have very little knowledge and mixed results concerning the effectiveness of digital environments and educational games for enhancing learning. In general, the effects of computer-assisted instruction (CAI) have been found to be small: $ES = 0.37$ (Hattie 2009).

This study investigated the effectiveness of one such game, Lola’s World, on the early numeracy learning of children with low socioeconomic family backgrounds and low early numeracy skills.

**Early numeracy skills**

Knowledge about the development of early numeracy skills and their relevance for later mathematics learning has increased rapidly over the last ten years (Aunio and Räsänen 2015; Fritz et al. 2013; Krajewski and Schneider 2009). In general, numeracy performance in early childhood years adequately predicts later mathematics performance (Jordan, Glutting and Ramineni 2010). In particular, counting skills (Aunio and Niemivirta 2010; Hannula-Sormunen et al. 2015; Krajewski and Schneider 2009; Jordan et al. 2010; Nguyen et al. 2016), basic arithmetic skills (Aunola et al. 2004; Jordan et al. 2010; LeFevre et al. 2010), number reading (Passolunghi et al. 2007; Vanbinst et al. 2015), number line acuity (Friso-van den Bos et al. 2015; LeFevre et al. 2010), magnitude comparison (LeFevre et al. 2010; Toll et al. 2015; Vanbinst et al. 2015), spontaneous focusing on numerosity (Hannula-Sormunen et al. 2015) and numeracy-related logic (Aunio and Niemivirta 2010) have
been found to be good predictors of later mathematics performance. Studies have shown that there are individual differences in early numeracy and that the differences in mathematics performance tend to continue in comprehensive school; thus, children who enter kindergarten with low performance in numeracy skills continue to lag behind their peers in future school years (Aunola et al. 2004; Duncan et al. 2007; Jordan et al. 2006; Jordan et al. 2010; Morgan et al. 2009). These results highlight the relevance of early interventions for low-performing children who are at risk for mathematical learning difficulties later at school.

Low performance in mathematics can be caused by several factors, including differences in cognitive functions or inadequate opportunities for learning essential mathematical skills (Geary 2013a). For instance, children from families with low socioeconomic status (SES) have been shown to exhibit lower early numeracy performance than children from middle-income families (DeFlorio and Beliakoff 2015; Jordan and Levine 2009; Morgan et al. 2016). Low performance in early childhood numeracy skills can be seen, for instance, in poor and/or slowly developing counting, enumeration and numerical relational skills (Aunio and Niemivirta 2010; Jordan et al. 2010).

To detect low performance—and, hence the risk for later mathematical learning difficulties—research has used various cut-off points (e.g. below the 15th percentile, below the 25th percentile and below the 35th percentile) in mathematical test performance (Geary 2013b). In particular, during early childhood, low performance is more relevant as a risk factor than diagnosing mathematical learning difficulties (MLDs), since the criteria for MLDs arise from the learning difficulties faced by school-age children (ICD-10: World Health Organization, 2016). However, the early identification of those children at risk for learning difficulties (i.e. low
performance) is highly essential, since research has shown that early intervention is an effective way of supporting learning in low-performance groups (Toll and Van Luit 2014; Wang et al. 2016), especially of children with low SES backgrounds (Ramani and Siegler 2011; Starkey et al. 2004), and of potentially preventing later learning difficulties.

**Computer-assisted instruction (CAI) in mathematics**

Reviews of the effects of computer-assisted instruction (CAI) on enhancing mathematics learning in heterogeneous populations of children have revealed small to moderate effects. On an elementary school level (Slavin and Lake 2008), effects were found when CAI was used as supplementary instruction ($ES = 0.19$) in light and short practice (approximately 30 minutes, three times a week), with the biggest effects manifesting for lower grades and, especially, arithmetic. In a comprehensive school comprising grades K through 12, CAI’s general effect was found to be small ($ES = 0.16$) (Cheung and Slavin 2013), particularly when used as supplementary education ($ES = 0.18$), as a computer management learning program ($ES = 0.08$), or as a comprehensive program, including CAI and non-computer activities ($ES = 0.07$). In addition, Cheung and Slavin (2013) reported similar effects for children of both low and high socioeconomic status. With regard to intensity, instruction of over 30 minutes per week ($ES = 0.20$) was more effective than instruction of less than 30 minutes per week. Li and Ma (2010) found in their meta-analysis an overall moderate effect of CAI on mathematics achievement in grades K through 12 ($ES = 0.71$). They also found that the use of CAI further enhanced mathematics achievement when it was used in elementary school students, with special needs students, or in combination with a constructivist approach to teaching. Xin and Jitendra (1999) reported that CAI is effective in lower grades, especially in arithmetic and problem
solving tasks. Furthermore, CAI has been found to be effective for students with learning difficulties (Chodura et al. 2015; Kroesbergen and Van Luit 2003; Li and Ma 2010; Miller et al. 1998; Xin and Jitendra 1999). The effects of CAI, compared to the effects of teacher-mediated instruction, have been mixed: Either CAI has been shown to be effective (Kroesbergen and Van Luit 2003) or no differences have been found between the two instruction formats (Bryant et al. 2015; Chodura et al. 2015). Although the number of intervention studies using CAI is increasing, there is still a lack of studies using comparable control groups, measuring the same skills with the same measurements (Räsänen et al. 2009).

Recently, only a few CAI intervention studies have focused on the early numeracy skills of young children (i.e. before the beginning of formal schooling) at risk in their mathematical learning (Baroody et al. 2012; Foster et al. 2016; Praet and Desoete 2014; Räsänen et al. 2009; Salminen et al. 2015a; Salminen et al. 2015b; Schacter et al. 2016b; Schacter and Jo 2016a; Wilson et al. 2009). A summary of these studies is presented in Table 1. Overall, these studies have primarily reported improved numeracy skills, at least in one of the measured numeracy skills, in the samples of children with low early numeracy skills. Their results show that children’s numeracy skills can be improved through rather short interventions (3 to 6 weeks), although greater effect sizes have been found for longer intervention phases (10 to 15 weeks). The sample sizes in most studies have been rather small; thus, generalisation of the results is of concern.

The number of CAI studies related to mathematics learning in children having difficulties in mathematics learning seems to be somewhat greater among school-aged children (see the meta-analyses of Chodura et al. 2015; Kroesbergen and Van Luit 2003; Li and Ma 2010; Miller et al. 1998; Seo and Bryant 2009; Xin and
Jitendra 1999 and the recent studies of Baroody et al. 2013; Käser et al. 2013; Nordness et al. 2011; Obersteiner et al. 2013; Ok and Bryant 2016). In summary, the number of CAI intervention studies is rather limited, and these studies have mostly provided positive improvements among school-age children at risk for or having difficulties in mathematics learning.

The present study

There is a lack of scientific knowledge of the effects of early numeracy educational computer games on the learning of young children who are at risk of mathematical learning difficulties (i.e. showing low early numeracy performance). Mathematical skills interventions for children with low performance due to environmental risk factors (e.g. low socioeconomic status) have been studied more commonly in the United States than in European countries (e.g. Dyson et al. 2011; Siegler and Ramani 2008). In addition, there is a shortage of studies integrating CAI into the daily learning routines of young kindergartens implementing an intervention-control group design with a pre-post-test design (Räsänen et al. 2009; Schacter and Jo 2016), thus increasing the ecological validity of the present study.

The research question in this study was as follows: What are the effects of playing the Lola’s World educational game on low-performing children’s early numeracy skills?

Method

Participants

The study was conducted in the metropolitan area of Helsinki, Finland. All three participating preschools were located in the area of positive discrimination. In the Finnish educational context, the positive discrimination index refers to poor
environmental factors, such as low parental education levels, unemployment, single-parent families, and a high number of immigrant families. In the beginning of the study, educators from the preschools identified a total of 33 children ($M_{age}$ 5.7 years, $SD = 5.1$ months) whom they thought would be low-performing in early numeracy skills. Of these 33 children, 23 were split randomly into two groups: an intervention group playing the numeracy game Lola’s World ($n = 12$) and an active control group playing a game for practicing early reading skills, Lola’s ABC party ($n = 11$). The remaining 10 children formed a passive control group ($n = 10$). When we compared the children’s Early Numeracy Test performance (see the Measurement section for the test description) with the test norms, we found that the real number of low-performing children ($-1.0$ $SD$ below the age-relevant mean score) was 22. Only these children were included in the analyses. The final groups were, thus, as follows: seven children playing Lola’s World, eight children playing Lola’s ABC party, and seven children forming a passive control group. Descriptive information is presented by group in Table 2.

**Measurement**

*Early numeracy skills*

The standardised Early Numeracy Test (Van Luit et al. 2006) was used in this study. The main purpose of the Early Numeracy Test is to identify children aged between four and seven years who are suspected of a delay in preparatory mathematics knowledge. The test takes a developmental perspective on children’s early numeracy skills and seeks to tap eight aspects of numerical knowledge. The mathematical relational skills part of the test (ENT relational) includes tasks related to the concepts of comparison, classification, one-to-one correspondence, and seriation. The counting skills part of the test (ENT counting) includes tasks related to the use of number
words, structured counting, resultative counting, and a general understanding of numbers. There are five items for each topic, yielding a total of 40 items. The test is given individually and takes about 30 minutes for a child to complete. The items are scored by giving one point for a correct answer and zero for a wrong answer. The children are not given feedback on whether their responses are correct or incorrect. The reliabilities in this sample for the total score (ENT total) in terms of the Cronbach’s alpha coefficient for three measurement times were .89, .89 and .87, respectively.

*Nonverbal reasoning*

Children’s nonverbal reasoning skills were measured using Raven’s Coloured Progressive Matrices (Raven 1965). The test included three sets of 12-item series. For each item, the child was tasked with identifying, from among the six choices, the missing element to complete the pattern. Two practice items were not included in the analyses; thus, the maximum score was 34 points. The Cronbach’s alpha determined from a previous study with a larger sample was acceptable ($\alpha = .77$; Authors).

*Observation logbook*

Preschool educators observed the children while they were playing the educational games. They focused on observing the children’s interest and motivation towards playing: Was a child concentrating on playing the game? Was the child mainly surfing with the game? Did the child refuse to play? In addition, educators marked the length of time each child was playing per session.

*Family background information*

Using a questionnaire, in the beginning of the study, we asked parents about their education level and home language (Table 2). In both the total sample and the subsamples, the maternal and paternal educational levels were lower than those of the
average Finnish population (Finnish Official Statistics, 2013). Several different native languages (e.g. Finnish, Kurdish and Chinese) were used in children’s homes. Kruskal-Wallis tests with post hoc comparisons showed no statistically significant differences between the groups (Lola’s World, Lola’s ABC, controls) in terms of home language or maternal or paternal education level.

**Intervention games**

In this study, two Lola Panda games (Beiz: http://www.lolapanda.com/index.html) were used. Lola’s World [Lolan suuri seikkailu] focuses on the practice of early numeracy skills, and it was played in the intervention group. Lola’s ABC Party [Lolan ABC-juhlat] targets early reading skills, and it was used in the active control group.

Lola’s World is designed for three- to six-year-old children. The focus is on early numeracy skills in number range from 1 to 10. More specifically, the game includes practice activities for the comparison of size, the categorisation of objects, the recognition of shapes and colors, the understanding/recognition of number symbols, numerosity and number symbols, the seriation of quantities and numbers, enumeration, and simple addition problems with number symbols. Most of the task instructions are given to the child verbally or visually. In the game, the child travels from island to island with the assistance of Lola Panda. The child solves tasks and receives rewards, which take the form of pieces of treasure maps. After collecting all pieces of the map, the child can open the treasure box. As a break time activity in the game, the child can, for example, decorate his/her house, change the clothes worn by his game avatar or draw a picture. The game is adaptive, and its starting level can be easy, medium or difficult.
Lola’s ABC Party is designed for children aged four to seven years. It is designed to help children practice foundational reading skills through interactive tasks. The game is adaptive. The child begins with the recognition and writing of vowels. Then, after successful practice, the child proceeds to tasks for practicing the same skills with consonants. After practicing the alphabet, the child begins to practice with words. Like Lola’s World, this game includes break time activities.

**Procedure**

This study follows a quasi-experimental intervention research protocol with a pre-test and immediate and delayed posttests. Three preschools in the area of positive discrimination were approached and asked about their willingness to participate. The research permits were requested and received from the city, the preschools and the parents of the children. The educators in the preschools were asked to identify those children who they thought would be low-performing in early numeracy and who, thus, might benefit from the intervention. At the beginning of the study (February 2015), the children’s early numeracy and nonverbal reasoning skills were measured. These measurements were done individually with each child in a separate room in his or her own preschool, and they were taken by the second author and a trained research assistant. One preschool wanted to participate in the study without the intervention; thus, the children in the two remaining preschools were divided randomly into the intervention group and the active control group. The game was played for 15 minutes every day for three weeks. The goal was to have, together, approximately four hours of game time for each child. The Beiz company provided the preschools with ten tablet computers with headphones. Two to three children used each tablet, and each child had his/her own profile in the game. The game play was integrated as part of the preschool day. The educators were instructed briefly on how the tablet computers and
the games worked before the intervention phase. When the children were playing the
games, the educators were asked to observe the children’s motivation and interest
using an observation blanket. After the intervention phase, the children’s early
numeracy skills were measured immediately and then one month after intervention.

**Data analysis**

Due to the small sample size of this study, non-parametric tests were used in the data
analysis. Kruskal-Wallis tests with post hoc comparisons were performed to
determine the between-group differences (Lola’s World, Lola’s ABC, controls) in
maternal and paternal education level and home language (see the Family background
information section), in Raven, and in Early Numeracy Test scores (i.e. ENT total,
ENT relational, ENT counting) at three different time points. Furthermore, Kruskal-
Wallis tests were used to compare the groups’ ENT gains between the time points of
the pretest and the immediate posttest and the pretest and the delayed posttest. The
Wilcoxon signed-rank test was used to analyse the within-group effects in ENT
performance (Lola’s World, Lola’s ABC, controls), which were interpreted with
exact, one-tailed \( p \) values. Effect sizes for statistically significant results were
calculated as Pearson’s correlation coefficient \( (r) \) using the following formula
(Rosenthal, 1991): \( r = z / \sqrt{N} \), where \( z \) is the \( z \)-score value produced from the analysis
and \( N \) is the total number of observations.

**Results**

The performance means and group differences in Raven, ENT total score and ENT
subscale scores by group at the three measured time points are reported in Table 3.
The Kruskal-Wallis test confirmed that there were no statistically significant
differences (all \( p \)-values > 0.05) among the three groups at the beginning of the
intervention in Raven, ENT total, ENT relational, or the ENT counting scales.
The effects of game playing on early numeracy performance

The Kruskal-Wallis test revealed no statistically significant differences (p > .05) among the three groups in terms of ENT total, ENT relational, or the ENT counting scales at either the immediate or the delayed posttest times. Neither were differences in gain scores found from pretest to immediate posttest or from pre-test to delayed posttest in any of the scales between the groups.

The only statistically significant results were found when analysing the within-group effects. The Wilcoxon tests showed a significant group-level improvement between the pre-test and the posttest in the ENT whole scale for the Lola’s World group (Z = -2.226, p = .016, r = .59) and for the controls in the ENT counting scale (Z = -2.207, p = .016, r = .59) (Table 3). No other statistically significant improvements were found within the groups.

Concentration and time of playing the games

The educators reported the children were concentrating on playing for 99% of their playing time. There was no “restless surfing” during their playing time with the game. The only distraction during playing occurred when a child wanted to show an educator or a peer how he was playing (1% of playing time). The educators reported that the children’s total time playing Lola’s World was 186.57 minutes (SD = 20.21) and that their total time playing Lola’s ABC was 183.50 minutes (SD = 22.70). There were no statistically significant differences (p > .05) between the intervention group and the active control group in terms of playing time.

Discussion

The aim of this study was to investigate the effects of the educational game Lola’s World on low-performing children’s early numeracy skills. The intervention phase
lasted three weeks (15 minutes daily game time). The study was conducted in public preschools in the positive discrimination area (i.e. low ses-area). A quasi-experimental intervention-control group design with pre- and posttest measurements was applied. We found that the early numeracy skills of low-performing children in the intervention group using the Lola’s World educational computer game increased statistically significantly from pretest to immediate posttest. However, between-group comparisons (i.e. among the numeracy intervention Lola’s World group, the active control Lola’s ABC group and the control group) revealed no statistically significant differences between early numeracy scores or in gains scores at any of the three time points. Although children’s group where small, as has been common in CAI interventions with low performing children (Salminen et al. 2015a; Salminen et al. 2015b), they were comparable in terms of nonverbal reasoning, early numeracy skills before intervention and time of playing. To be able to contribute to the existing knowledge we used the same early numeracy measurement in all measurement times (Räsänen et al. 2009). To secure the ecological validity of the study we did the study in preschools as part of children’s daily activities (Räsänen et al. 2009; Schacter and Jo 2016). It can be that our results demonstrated that it is quite challenging to get good intervention effects on children’s skills with short term game intervention when several methodological requirements are fulfilled.

*Low-performing children need extensive explicit and structured instruction*

Our results are in line with the study of Salminen and her colleagues (2015a), who showed within-group improvements for the intervention group, but no between-group differences. The reason for this lack of statistically significant effects between groups may be that low-performing children need a great deal of practice to learn basic skills (Geary 2013b). Although previous studies using a three-week practice times, as was
used in this study, have indicated similar learning effects (e.g. Salminen et al. 2015a), increasing the practice time might yield better effects (e.g. Schacter et al. 2016b). The Lola’s World game was originally developed to help average-performing children practice basic early numeracy skills (Beiz). In this study, it was used with children from families with low SES; furthermore, within this sample, we concentrated on children identified as low-performing in early numeracy skills. Using an educational game in different types of populations of children showing low performance, such as populations with different measured numeracy performance levels (Praet and Desoete 2014) or socioeconomic status (e.g. Schacter and Jo 2016a), may yield different results, since the reasons behind the low performance may differ (Geary 2013a). For some children, the reason for low performance may have been a lack of adequate early childhood numeracy experiences (i.e. for children with low SES) (Morgan et al. 2016), while for others, the reason may have been more cognitive (Geary 2013b). In the first case, exposure to quality numeracy instruction may yield a more rapid increase in learning than in the latter case.

In order to support early numeracy learning in low-performing children, educational games should have a good research-based structure (e.g. Aunio and Räsänen 2015), so that the most essential skills are practiced enough and so that tasks follow one another in a developmentally valid order (e.g. Foster et al. 2016). In addition, mathematics educational games have been found to include rare instructional elements that are considered beneficial for low-performing children’s learning, such as explicit and structured instruction (Seo and Bryant 2009). In order to make Lola’s World, and any other CAI program, more suitable for low-performing children, these elements should be taken into consideration.

*Child’s interest and motivation in playing and shared learning experiences*
Both games used in this study, Lola’s World and Lola’s ABC, were interesting and motivating for the children. Educators reported no need to motivate the children to play the games during the preschool day (15 minutes per day for three weeks). In fact, the educators reported the interesting phenomenon that the children often wished to show their educator or peers how they were playing. This kind of shared learning using tablet computers has been previously reported in the early childhood context (Khoo et al. 2015). The related term is peer-assisted learning, which has shown some positive results in supporting learning in mathematically low-performing children (Baker et al. 2002; Kunsch et al. 2007) however, so far, most results come from older students.

Limitations of the study and future challenges for game-based learning

The main limitation of this study was its small sample size, which limits the generalisability of the results. However, the study represents a valuable attempt to integrate game-based support into the average preschool days of low-performing children, as proposed in a recent review (Räsänen 2015). The study also gives us guidelines for future research. In future studies with bigger samples, it might be interesting to either increase the instruction time (weeks) or combine the use of the Lola’s World game with small-group supplemental instruction. Also of interest would be to investigate the possibility of increasing the children’s play time outside preschool hours, so that they could practice relevant skills at home. This would, however, require the children to have access to digital equipment (either a tablet computer or a smart phone) and, possibly, an Internet connection. This might be a problem for children coming from families with low socioeconomic status.

Developing educational games requires good collaboration among game developers and researchers. It is essential to apply good research designs to
investigate the effects of playing games on not only children’s performance, but also their motivation and interest. Although, in this study, there were few positive results to report, future research should continue to explore who will benefit from educational games and what is the most efficient way to use these games with children.

**Conclusion**

Playing the Lola’s World numeracy computer game daily for three weeks improved the within-group early numeracy skills of low-performing children; however, no statistically significant differences among this group, the group playing a game practicing early reading skills, and the passive control group, were found in either the posttest scores or the gain scores. The Lola’s World game might work better with increased instruction time or in a different type of population (e.g. children with no problems in learning numeracy skills); therefore, further research on the effects of this game in these scenarios would be highly interesting.


<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Country</th>
<th>Name of the game</th>
<th>Skills practiced</th>
<th>Participants (N)</th>
<th>Status</th>
<th>Mean age (years)</th>
<th>Setting</th>
<th>Outcome measure(s)</th>
<th>Main results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baroody, Eiland, Purpura, &amp; Reid</td>
<td>2012</td>
<td>USA</td>
<td>(no name)</td>
<td>Recognizing the $n + 0/0 + n = n$ and the $n + 1/1 + n = $ the-number-after-$n$ rules</td>
<td>15</td>
<td>At risk (either low-performing or having another risk factor)</td>
<td>5.58</td>
<td>Stage 1: 10 weeks, 2 x 30 min per week; Stage 2: 9 weeks, 2 x 30 min per week</td>
<td>TEMA-3, mental additions</td>
<td>Intervention group outperformed the active control group ($n = 14$) on both practiced and unpracticed ($n + 0/0 + n$ and $n + 1/1 + n$ items and had larger gains in TEMA-3 ($d = 0.92$).</td>
</tr>
<tr>
<td>Praet &amp; Desoete</td>
<td>2014</td>
<td>Belgium</td>
<td>(no name)</td>
<td>Group A: Comparison of visual and auditory quantities; Group B: Procedural and conceptual counting</td>
<td>Group A: 39 Group B: 44</td>
<td>average and low performing</td>
<td>5.7</td>
<td>8 sessions of 25 min. over 5 weeks</td>
<td>TEDI-MATH: calculation; Number Knowledge (NK); Kortrijk Arithmetic Test Revised (ARIT)</td>
<td>TEDI-MATH: Group B outperformed Group A, and both intervention groups outperformed controls (posttest). NK: Both intervention groups outperformed controls (Grade 1). ARIT: Group B outperformed controls (Grade 1). Low-performing and average-performing benefited similarly from the intervention.</td>
</tr>
<tr>
<td>Räsänen, Salminen, Wilson, Aunio, &amp; Dehaene</td>
<td>2009</td>
<td>Finland</td>
<td>The Number Race and The Graphogame-Math</td>
<td>Group A: In the Number Race, numerical comparisons; Group B: In Graphogame-Math, matching of verbal labels to visual patterns and number symbols</td>
<td>Group A: 15 Group B: 15</td>
<td>low performing</td>
<td>6.6</td>
<td>10-15 min. daily for 3 weeks</td>
<td>Verbal counting, object counting, number comparison, arithmetic</td>
<td>Group B showed significant improvement in number comparison skills compared to average-performing controls.</td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Country</td>
<td>Intervention</td>
<td>Task</td>
<td>Group Size</td>
<td>SES</td>
<td>Sessions</td>
<td>Outcome</td>
<td>Notes</td>
<td></td>
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<tr>
<td>Wilson, Dehaene, Dubois, &amp; Fayol</td>
<td>2009</td>
<td>France</td>
<td>The Number Race</td>
<td>Numerical comparisons</td>
<td>53 divided into two groups: one group practiced first the Number Race and then reading tasks; the second performed these tasks in reverse</td>
<td>–</td>
<td>low SES</td>
<td>5.6</td>
<td>6 sessions of 20 min over 14 weeks (incl. also 4 sessions of reading instruction as a cross-over design)</td>
<td>Verbal counting, object counting, non-symbolic numerical comparison, digit numerical comparison, verbal numerical comparison, cross-format number matching, and addition</td>
</tr>
<tr>
<td>Salminen, Koponen, Leskinen, Poikkeus, &amp; Aro</td>
<td>2015</td>
<td>Finland</td>
<td>The Graphogame-Math</td>
<td>One-to-one correspondence, approximate and exact comparison, ordering, number word-quantity mapping, object counting, composing, decomposing and addition</td>
<td>13</td>
<td>low performing</td>
<td>6.5</td>
<td>4–5 sessions of 10–15 min per week over 3 weeks</td>
<td>Enumeration, verbal counting, Number Sets Test, basic addition</td>
<td>Significant within-group improvements were observed in basic addition ($r = 0.59$), verbal counting ($r = 0.56$), and the Number Sets Test ($r = 0.45$). No difference in gains were observed compared to controls receiving another type of numeracy instruction.</td>
</tr>
<tr>
<td>Salminen, Koponen, Räsänen, &amp; Aro</td>
<td>2015</td>
<td>Finland</td>
<td>The Number Race and The Graphogame-Math</td>
<td>Group A: In the Number Race, numerical comparisons; Group B: In Graphogame-Math, matching of verbal labels to visual patterns and number symbols</td>
<td>Group A: 8 Group B: 9</td>
<td>low performing (Participants same as in Räsänen et al., 2009, but including only those performing &lt; 10th percentile)</td>
<td>6.6</td>
<td>10-15 mins. daily for 3 weeks</td>
<td>Verbal counting, object counting, arithmetic</td>
<td>Group A: A significant within-group effect in arithmetic ($r = 0.63$) was observed; Group B: A significant intervention effect in verbal ($r = 0.46$) and in object counting (dot counting, $r = 0.52$) was observed. Group A outperformed Group B in arithmetic ($r = 0.56$)</td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Country</td>
<td>Intervention</td>
<td>Number Sense (Subitizing, Counting, Sequencing Quantities, Numerical Identification, Matching Numerals and Quantities, Sequencing Numerals and Quantities, Comparing Quantities and Numerical Magnitudes, Addition Within 6, and Number Composition and Decomposition to 100)</td>
<td>Sample Size</td>
<td>SES</td>
<td>Frequency</td>
<td>Duration</td>
<td>Test Description</td>
<td>Results</td>
</tr>
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<tr>
<td>Schacter &amp; Jo</td>
<td>2016</td>
<td>USA</td>
<td>Math Shelf</td>
<td>Number sense (subitizing, counting, sequencing quantities, numerical identification, matching numerals and quantities, sequencing numerals and quantities, comparing quantities and numerical magnitudes, addition within 6, and number composition and decomposition to 100)</td>
<td>173</td>
<td>low SES</td>
<td>2 days a week, for 10 min a session, for 15 weeks</td>
<td>iPad number sense test (quantity discrimination, numerical identification, numeral sequencing, cardinal principle, comparing quantities, matching numerals to quantities)</td>
<td>Intervention group outperformed controls (doing regular preschool math activities) in number sense ($d = 1.09$).</td>
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<tr>
<td>Schacter, Shih, Allen, DeVaul, Adkins, Ito, &amp; Jo</td>
<td>2016</td>
<td>USA</td>
<td>Math Shelf</td>
<td>Number sense (subitizing, counting, sequencing quantities, numerical identification, matching numerals and quantities, sequencing numerals and quantities, comparing quantity and numerical magnitudes)</td>
<td>50</td>
<td>low SES</td>
<td>3 days a week, for 10 min a session, for 6 weeks</td>
<td>iPad number sense test (quantity discrimination, numerical identification, numeral sequencing, cardinal principle, comparing quantities, matching numerals to quantities)</td>
<td>Intervention group outperformed controls (playing other commercial math apps) in number sense ($d = 0.57$).</td>
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Table 2. Background Descriptives by Group.

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<td>Lola’s ABC</td>
<td>Controls</td>
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<tr>
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<td>Age (months)</td>
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