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A Pilot Study about the Effect and Sustainability of Early Interventions for Children with Early Mathematical Difficulties in Kindergarten

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The purpose of the present pilot study was to evaluate the effects of particular educational math games in kindergarten on numerical skills in Grade 1. Our participants were 49 children with early math difficulties, 65 average achievers, and 48 high-achieving 5-year-old children. All of them played various adaptive math games for 5 weeks. To avoid the Hawthorne effect, 37 children engaged in non-math-related games whereas the other children played counting, comparison, or numerical working-memory games. The results indicated that the effect of working memory and combined counting and comparison games continued until January of Grade 1. At the end of Grade 1, about 87% of the children with learning problems that had participated in the working memory game in kindergarten performed average on arithmetic skills. The present pilot study shows that children at risk of math disabilities can benefit greatly from the use of certain games to prevent learning difficulties.

Introduction

Increasing evidence shows that basic aspects of mathematical understanding are present early in development and prior to explicit instruction (Bonny & Lourenco, 2013). Young children's early educational experiences seem to have an impact on later outcomes (Sylvia, 2009) in terms of educational achievement but also in their attitudes toward subjects (Glauert & Manches, 2013).

Several variables have turned out to be relatively important cognitive predictors of later arithmetic achievement. Research has evidenced the importance of counting (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Stock, Desoete, & Roeyers, 2010) and comparison skills (e.g., De Smedt et al., 2013). In addition, Diamond (2013) mentioned that during childhood years, working-memory capacity increases rapidly, as well. Strong correlations between working memory and mathematics have been evidenced in preschool (Bull, Espy, & Wiebe, 2008; Kroesbergen, Van Luit, Naglieri, Franchi, & Taddei, 2010; Kyttälä, Aunio, & Hautamäki, 2010) and during early school years (Lee & Bull, 2016; Toll, Kroesbergen, & Van Luit, 2016). In addition, working memory impairments have been found in the screening of children with mathematical learning disabilities (De Weerdt, Desoete, & Roeyers, 2013; Geary, 2011; Rotzer et al., 2009; Wilson & Swanson, 2001).

Previous studies have revealed that early numeracy may be stimulated (Kuhn et al., 2017; Praet & Desoete, 2014; Salminen, Koponen, Leskinen, Poikkeus, & Aro, 2015; Schacter et al., 2016). Playing educational counting games (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009; Wilson et al., 2006) might even buffer against poor arithmetic outcomes. However, several questions remain unanswered given

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that whereas low performing children were found to benefit from a large amount of "additional education" (e.g., Dyson, Jordan, & Glutting, 2013), it remains unclear whether they also benefit from didactic methods using educational computer games and from less intensive support organized in an inclusive way.

In addition, the effectiveness of working-memory training programs remains a subject of debate. A meta-analysis by Melby-Lerväg and Hulme (2013) revealed that training effects cannot be generalized and that the effects are only evident for content that had been trained before. In addition, Harrissin et al. (2014) demonstrated that a working-memory training is useful as long as the actual task resembles the training task. However, the training program developed by Passolunghi and Costa (2016) involved working memory and early numeracy for five weeks resulted in an improvement in preschool children's early numeracy abilities whereas working memory intervention improved not only working memory abilities but also early numeracy abilities. Also, Kirk et al. (2017) revealed that children with intellectual and developmental disabilities receiving a computerized cognitive training show no visible training effects. However, their numerical skills improved significantly in the follow-up measurement three months later. In addition, Li (2017) showed that a visual-filtering efficiency training is beneficial for verbal working-memory span. These gains were upheld at a 3-month follow-up test. Moreover, it seems important to focus on mathematical content because number sense training enhances arithmetic whereas a training on working memory enhances word-problem solving skills in elementary school children (Kuhn & Holling, 2014). However, this effect was no longer present after the summer holidays (Kuhn et al., 2017). Consequently, the effectiveness and sustainability of working-memory training programs remains a subject of debate.

In the current study, we investigated whether by challenging children's working memory abilities in kindergarten we may give numeracy development in Grade 1 a boost. We have specifically aimed to examine the effect of child-friendly computer games on working memory in children with early-math problems and on average and good performers. Moreover, the durability of such a stimulation in kindergarten is investigated at the end of Grade 1.

Method

Participants

Children, their parents, and their teachers were recruited from regular kindergarten schools (no schools with special education have been included) in Belgium. Parents of 165 children provided written informed consent in kindergarten. In this study, 160 children were monolingual Dutch-speaking, and two children were bilingual. Also, 159 lived in families that had an income above the poverty line. All children participated in the follow-up measurement in the middle and at the end of Grade 1. Children in Belgium enter elementary school at age 6 or 7. When children had a score below the 25th percentile on early numeracy, they were considered *children with learning problems.* With a score above the 25th percentile, children were considered *average or good performers.*

Intervention

After the pretest in kindergarten, children were randomly assigned to one of the five gaming interventions: a *counting only* group (playing serious counting games; $N = 43$), a *comparison only* group (playing serious number comparison games; $N = 38$), a *working memory* condition combined with counting and comparison games ($N = 19$), or a *combined counting and comparison* condition ($N = 15$). In addition, 47 children participated in the study as an active business-as-usual control group. The study was carried out for two school years.

During the first year, children were randomly assigned to three conditions: a counting group, a comparison group, and a control group. In the second year, combined and working-memory conditions were added.

The serious games took place in nine individual gaming sessions in a separate classroom for 5 weeks, 25 min each time. Multiple treatments were administered at each school. Each session consisted of solving problems in accordance with the instructions given in the game. The game had an adaptive structure: Children received exercises on the components they had experienced as difficult, and they learned by playing the game. The game incorporated a dynamic element, as it adjusted to the child's level of ability and configured further levels in accordance with this ability. This adaptation prevented frustration, and positive feedback maintained the child's interest in playing for a sufficient time to establish learning. Visual feedback was provided with a happy or a sad face. Auditory feedback was given in the form of a sob when they made a mistake or applause when they succeeded. Learning was fun, and the children were able to play by themselves.

In the counting only game condition, children played a game concerning procedural and conceptual counting knowledge. They were asked, "How many animals are there?" or "How many can bark?" with objects, plants, and animals on the screen. The instruction was read aloud, and the children answered by tapping the number of stars.

The comparison only game condition involved a nonintensive but individualized and adaptive game on number comparison. Children learned to focus on number and not on size. They learned to compare the number of animals by pointing the mouse at the group that contained the most animals, abstracting the size of the animals. In addition, children had to compare organized and unorganized stimuli (animals/dots).

In the mixed comparison and counting game condition, children started by counting. The game computer registered whether it was done correctly. Then, the children were presented a blending of the two interventions mentioned above.

In the working memory game condition, children received a working-memory training (lasting 10–15 min) in combination with a counting and comparison intervention. The children were given dual tasks: They had to remember and compare or count animals as well as the place and color of squares in combination with other tasks. For example, when a square turned white, the child had to solve a word problem (e.g., "Is nine a color?"). They had to answer *yes* or *no*. Only then did they point at the color and the place they had seen. Feedback was given with a sound based on their answer.

A control game group was included to prevent the Hawthorne effect (positive effects due to extra attention during gaming). Control subjects (the control group) received the same amount of instruction time as the children in the other two conditions. However, instead of counting or comparison instruction, the control group received nine enjoyable sessions of regular kindergarten activities (intervention as usual along with the opportunity to play some nonmath games on the computer).

> The inclusion of five groups is important to ensure that any treatment effect obtained by the serious games can be attributed to working memory (in the working-memory game group), counting (in the counting and in the combined counting and comparison game condition), or comparison (in the comparison and in the combined counting and comparison game condition) rather than other factors such as shifting in content (in working-memory game condition and in the combined counting and comparison game condition), solving arithmetic exercises (in the counting, comparison, working memory and combined counting and comparison condition), or just getting older (in all groups, including the control group).

Procedure and Measures of the Longitudinal Design

The study involved four moments of data collection. Parents received a letter explaining the study and submitted informed consent for their children to participate. All children were assessed individually, outside the classroom setting. The first measurement took place when the children were in kindergarten (as a pretest), before which the children were randomly assigned to one of the five groups (see Table 1). The second measurement took place just after the training in kindergarten (as the posttest; see Table 2). The third test for Grade 1 took place in January (as a delayed test, see Table 3). There was a final test of Grade 1 in June.

Pretest measures (assessed in kindergarten). Children's early numeracy was measured (at ages 5 to 6) using three subtests of the TEDI-MATH (Grégoire et al., 2004). Procedural counting knowledge (see Table 2) was assessed using accuracy in counting numbers, counting forward to an upper bound (e.g., "count up to 6"), counting forward from a lower bound (e.g., "count from 3"), and counting forward with an upper and lower bound (e.g., "count from 5 to 9"). One point was given for a correct answer. The internal consistency of this task was good (Cronbach's alpha = .73). Conceptual counting knowledge was assessed using judgments about the validity of counting procedures. Children had to judge the counts of linear and random patterns in drawings and counters. To assess the abstraction principle, children had to count different kinds of objects presented in a heap. Furthermore, a child counting a set of objects was asked, "How many objects are there in total?" or "How many objects are there if you start counting from the leftmost object in the array?" When children had to count again to answer these questions, it was considered to represent good procedural knowledge, but they proved a lack of understanding of counting principles, so they earned no points. One point was given for a correct answer (e.g., "You did not add objects, so the number of objects has not changed"). The internal consistency of this task was good (Cronbach's alpha = .85). Finally, children were presented with six calculation tasks in the form of pictures (e.g., "Here, you see two red balloons and three blue balloons. How many balloons are there together?"). Cronbach's alpha for this subtest was .84. The TEDI-MATH has been used and tested for conceptual accuracy and clinical relevance in previous studies (e.g., Stock et al., 2010).

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

Posttest measures (assessed in kindergarten). After the training (at the end of June in kindergarten), the posttest took place. Children completed the six calculation tasks as pictures (e.g., "Here, you see two red balloons and three blue balloons. How many balloons are there together?") of the TEDI-MATH (see 2.3.1). Cronbach's alpha was .84.

Follow-up measures (assessed in the middle of Grade 1). A follow-up test was given in January measuring arithmetic proficiency in Grade 1. At that moment, all children completed the Middle Grade 1 version of the Kortrijk Arithmetic Test Revised (Kortrijkse Rekentest Revision [KRT-R]; Baudonck et al., 2006). The KRT-R is a standardized arithmetic achievement test that requires children to solve 30 mental arithmetic (e.g., "16 – 12 = _") and 30 number knowledge tasks (e.g., "1 more than 3 is _"). A validity coefficient (correlation with school results) and reliability coefficient (Cronbach's alpha) of .93, respectively, were found.

Follow-up measures (assessed at the end of Grade 1). At the end of Grade 1, the children completed the End Grade 1 version of the KRT-R (Baudonck et al., 2006). Cronbach's alpha was .94.

Results

Preliminary Comparisons (Pretest Results)

No significant differences between the five groups in kindergarten were observed.

For *M* and *SD* of the pretest measures, see Table 1. All groups had children with learning problems and children with average and good numeracy skills (see Table 2).

Posttest Results in Kindergarten

The intervention groups diverged (F (4,157) = 20.318; $P < .001$; $ή^2$) regarding calculation proficiency in kindergarten. For *M* and *SD* on the pretest measures, see Table 3.

Table 1. ***Pretest skills in kindergarten***

	Control *N*=47	Counting only N=42	Comparison only N= 38	Working memory *N*= 19	Counting and comparison *N*= 15	*F* (4,157)=
Mean age in months	67.87 (4.02)	68.33 (3.83)	68.16 (3.93)	70.16 (4.82)	67.53 (4.07)	1.27
VIQ	102.55 (10.96)	102.58 (12.82)	104.11 (12.28)	101.89 (15.76)	108.07 (14.25)	0.69
PIQ	97.60 (12.57)	99.26 (10.17)	102 (11.82)	96.84 (15.89)	105 (13.35)	1.64
TIQ	100,47 (12,83)	100.98 (11,43)	103.66 14,06)	99.89 (15,91)	106,73 (10.36)	1.01
Procedural counting	6.47 (1.40)	6.30 (1.77)	6.61 (1.57)	5.74 (1.91)	5.60 (2.35)	1.57
Conceptual counting	10.13 (2.82)	9.70 (3.40)	10.42 (2.34)	8.42 (2.46)	9.53 (2.47)	1.79
Calculation	7.70 (4.93)	7.86 (5.43)	7.71 (4.99)	6.26 (5.27)	6.93 (4.68)	0.41

* $p < .05$

Table 2. ***Number of children in the different performance groups in kindergarten (pretest)***

Performance Level	Control (*n*=47)	Counting Only (*n*=43)	Comparison Only (*n*=38)	Working Memory (*n*=19)	Counting & comparison (*n*=15)
Children with learning problems	27.66% (*n* = 13)	27.91% (*n* = 12)	26.32% (*n* = 10)	42.10% (*n* = 8)	40% (*n* = 6)
Average achievers	48.78% (*n* = 20)	44.19% (*n* = 19)	42.10% (*n* = 16)	31.58% (*n* = 6)	26.67%. (*n* = 4)
Good achievers	29.79% (*n* = 14)	27.91% (*n* = 12)	31.58% (*n* = 12)	26.31% (*n* = 5)	33.33% (*n* = 5)

Table 3. ***Effect of a kindergarten gaming intervention at the end of kindergarten***

	Control	Counting only	Comparison only	Working memory	Counting& comparison	F(4,157)
Kindergarten Calculation	8.76d (3.29)	12.53c (3.08)	10.96c (3.10)	14.37b (4.02)	15.20a (2.00)	18.90*

* $p \leq .001$ abc posthoc indices p<.05

After the intervention in kindergarten, the combined comparison and counting group performed better than the group including working memory games. Both groups performed better than the isolated counting and comparison groups. Children who received mixed training obtained significantly higher calculation levels than children in the control group. Post-hoc analyses (Fisher's LSD) revealed that the isolated counting and comparison groups had better calculation skills than the active control children in kindergarten. In addition, the number of children with learning problems in the intervention condition decreased to 13.88%, whereas the spontaneous reduction in the control group was to 30.76% (see Table 4). The distributions of children with learning problems and of average and good performers in all conditions are presented in Table 4.

Follow-up results in the middle of Grade 1. The MANOVA using number knowledge and mental arithmetic assessed in Grade 1 (January), as dependent variables, was significant on the multivariate level ($F(8, 312) = 4.05$; $P < .001$; $\acute{\eta}^2 = .094$). Significant differences have been found between the groups for number knowledge ($F(4,157) = 7.51$; $P < .001$, $\acute{\eta}^2 = .161$) and mental arithmetic ($F(4,157) = 5.21$; $P = .001$; $\acute{\eta}^2 = .117$).

Table 4. ***Number of children in the different performance groups in kindergarten (posttest)***

Performance Level	Control (*n*=47)	Counting Only (*n*=43)	Comparison Only (*n*=38)	Working Memory (*n*=19)	Counting & comparison (*n*=15)
Children with learning problems	8,51% (*n* = 4)	4,65% (*n* = 2)	2,63% (*n* = 1)	5.26% (*n* = 1)	0% (*n* = 0)
Average achievers	56,59% (*n* = 36)	62,79% (*n* = 27)	76,31% (*n* = 29)	26.31% (*n* = 5)	33.33% (*n* = 5)
Good achievers	14.89% (*n* = 7)	32.56% (*n* = 14)	21.05% (*n* = 8)	68.42% (*n* = 13)	66.66% (*n* = 10)

Table 5. ***Effect of a kindergarten gaming intervention in the January of Grade 1.***

	Control	Counting only	Comparison only	Working memory	Counting and comparison	F(4,157)
Number Knowledge	19.23c (5.87)	22.58b (4.28)	22.34b (4.40)	24.79a (3.38)	24.80a (2.51)	7.51*
Mental Arithmetic	18.15c (6.54)	22.30a (4.98)	20.66b (5.40)	23.63a (4.50)	23.07a 5.82)	5.24*

* $p \leq .005$ abc posthoc indices p<.05

Children from the working memory CAI and from the combined counting and comparison CAI had better number knowledge and mental arithmetic scores than children in the control group (see Table 5). The four CAI groups had better number knowledge than the control group. The CAI on counting significantly differed from the control group in mental arithmetic. In addition, the number of children with learning problems in the different groups showed a significant difference (χ^2 (8,162) = 37.79; $P < .001$). There were more children with learning problems in the control condition (29.79%) compared to the other conditions (between 0% and 5.26%; see Table 6).

Table 6. ***Number of children in the different performance groups in Grade 1 January (follow-up test)***

Performance Level	Control	Counting Only	Comparison Only	Working Memory	Counting & comparison
Children with learning problems	29.79% (*n* = 14)	0% (*n* = 0)	2,70% (*n* = 1)	5.26% (*n* = 1)	0% (*n* = 0)
Average achievers	29.79% (*n* = 14)	41.86% (*n* = 18)	51.35% (*n* = 19)	15.78% (*n* = 3)	26.66% (*n* = 4)
Good achievers	40.42% (*n* = 19)	58.14% (*n* = 25)	48.64% (*n* = 18)	78.95% (*n* = 15)	73.33% (*n* = 11)

Follow-up results at the end of Grade 1. All of the children were tested again at the end of Grade 1, to investigate the durability of the intervention effect. No additional intervention took place in Grade 1. In this follow-up measure, the MANOVA was no longer significant for number knowledge ($F(4, 153) = .534$; $P =.711$) or for mental arithmetic ($F(4, 152) = .384$; $P = .820$). However, there was a trend in differences: the numbers of poor performers in the working memory and in the combined counting and comparison conditions were significant lower than that in the other groups (χ^2 (8,162) = 14.58; $P = .068$). The distribution of the children is presented in Table 7.

Table 7. ***Performance groups in Grade 1 (sustainability test)***

Performance Level	Control (*n*=47)	Counting Only (*n*=43)	Comparison Only (*n*=38)	Working Memory (*n*=19)	Counting & comparison (*n*=15)
Poor	42.55% (*n* = 20)	18.60% (*n* = 8)	28.95% (*n* = 11)	5,26% (*n* = 1)	20% (*n* = 3)
Average	40.42% (*n* = 19)	51.16% (*n* = 22)	44.74% (*n* = 17)	47.37% (*n* = 9)	46,67% (*n* = 7)
Good	17.02% (*n* = 8)	30.23% (*n* = 13)	26.32% (*n* = 10)	47.37% (*n* = 9)	33.33% (*n* = 5)

To conclude, 29.79% of the children in the control group had learning problems, whereas this was only the case for between 0% and 5.26% of the children in the intervention groups. In addition, at the end of Grade 1, seven out of eight (or 87%)

of the poor performers who received working-memory training in kindergarten performed average on arithmetic at the end of Grade 1.

Discussion

Previous research has shown a positive relationship between working memory and academic achievement in school-aged children after checking children's intelligence (e.g., Alloway & Alloway, 2010; De Weerdt et al., 2013). However, the results were not always consistent: some studies showed no or limited relationships between working memory and mathematics (Bull & Lee, 2014; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2014; Navarro, Aguilar, Alcalde, Ruiz, Marchena, & Menacho, 2011; Raghubar, Barnes, & Hecht, 2010). In addition, studies involving children with learning problems and studies focusing on the long-term effects or durability of interventions are lacking. The current findings have added this information to the existing literature.

In this study, we have investigated whether games in kindergarten involving working memory could boost numeracy development in kindergarten, so that children at risk could catch up before formal schooling. In addition, we looked at durability by studying the effects at four measurement points in low, average, and above average achievers.

Our results show that the early arithmetic skills of all children improved over time. However, we observed the greatest improvement in the group that played combined counting and comparison games in kindergarten (Tables 2 and 4). In addition, the children who received the working memory intervention also evolved. Our Grade 1 data collected in January revealed that games involving counting and comparison as well as those involving working memory in kindergarten have the potential to enhance the early arithmetic skills of young children.

When looking at children with learning problems, our data revealed that all four serious games in kindergarten improved the early numeracy of the children. All of the children started better prepared for Grade 1 compared to the control group of children who did not receive a numeracy intervention. The working memory intervention and the combined counting and comparison intervention resulted in the highest gain scores in the kindergarten posttest and in the Grade 1 follow-up test in January. Children with early learning problems who played a working memory or a combined counting and comparison game in kindergarten performed better than children who did not perform poorly in the control group in kindergarten, even 7 months after training, without additional training in between. This contradicts the findings that the effects fade due to summer holidays (Kuhn et al., 2017). In our study, of the eight children at risk in kindergarten who played the working game (see Table 2), only one average-intelligence (VIQ = 96; PIQ = 81; TIQ = 87) boy remained poorly performing after the games (see Tables 4, 6, and 7). Of the six children playing combined counting and comparison games, all of them had at least average skills until January of Grade 1 (see Table 4 and 6). However, three of them had problems at the end of Grade 1 (see Table 7). This might be because of the limited durability of short gaming interventions or the need for additional support to maintain improvement in children. Additional studies are needed to understand the reason why some children do and others do not improve through a gaming intervention.

All studies have their limitations.

The main limitation of this study is that the results are to be seen as a preliminary, exploratory, preparatory, and small-sample effort undertaken to decide whether a larger study is warranted. In this sample at the end of Grade 1, the general effects of 5 weeks of gaming during preschool disappeared, but 87% of the poor performers who played working memory games still performed average on arithmetic at the end of Grade 1. To conclude, the present study has found some evidence for the value of games to enhance numeracy at the beginning of Grade 1. Nevertheless, the study also reveals that it was not enough to only play for 5 weeks during kindergarten to ensure improvement at the end of Grade 1. Additional studies seem advisable.

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