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

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Abstract

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

Introduction

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

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

Early numerical skills

There is a growing body of research focusing on the possibility of stimulating the 'early numerical' or 'preparatory' skills or competences of young children (e.g. Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Greenes, Ginsubrg, & Balfanz, 2004; Kaufmann, Delazer, Pohs, Semenza, & Dowker, 2005; Morgan, Farkas, & Wu, 2009). In addition, the foundations of numeracy have been receiving ongoing attention. Researchers hope that by structured, early interventions supporting numeracy-related learning the problems might be reduced or even solved by providing at-risk children optimal opportunities to improve their knowledge and skills, preventing them from falling further behind (Clements & Scarama, 2011; DiPema et al., 2007; Fuchs, 2011; Ramey & Ramey, 1998). Often, the aims of studies are to drastically reduce problems in learning outcomes (and the need for special education), as well as the negative, long-term effects, which occur when children leave school without the skills they need to function in their later life (Toll, 2013).

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

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

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

Mapping and arithmetic

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

Interventions in early numeracy skills

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

Although early childhood education has been historically designed as child-centred and nurturing, educational standards for early childhood teachers are rising with an intensification of teaching and a shift to program purposes even in young children (Bullough et al., 2014). Several **purposeful instructions** were found effective in the enhancement of early numeracy in young children (Bullough, Hall-Kenyoun, MacKay, & Marshall, 2014; Dobbs, Doctoroff, Fisher, & Arnold, 2006; Griffin, 2004; Jordan, Glutting, Dyson, Hassinger-Das & Irwin, 2012; Klein & Starkey, 2008; Kroesbergen & Van Luit, 2003; Van Luit & Toll, 2013). Clements' study (1984) already revealed that classification and seriation were effective compared to the control condition, but that counting intervention had the highest power. In addition, Clements and Sarama (2007; 2009) developed and demonstrated the effectiveness of the 'Building Blocks' mathematics curriculum for young children.

Number activities, such as counting, number recognition and number comparison, were specifically taught in a 26-week instructional program. This program looked to measure early mathematical knowledge and resulted in the experimental group reaching a higher level than the control group.

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

In addition, several intervention studies were set up using '**games**'. Shaffer and Gee (2005) noticed that 'knowledge games', where students are asked to do things in a structured way (epistemic games), could serve education (Salamani

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

Moreover, **educational software** in the form of ‘**serious games**’ or ‘Computer Assisted Interventions' (CAI) has received growing interest (e.g. Niederhauser & Stoddart, 2001; Regtvoort, Zijlstra, & Van der Leij, 2013). There are already over 1000 apps on the iPad tagged for kindergarten (Glauert & Manches, 2013). International institutions, like the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2008), have advised and promoted the use of

Information and Communication Technology (ICT) for teaching and learning (Rolando, Salvador, & Luz, 2013). Literature reviews showed that the use of ICT in teaching has a strong motivational effect on students (Lee et al., 2011). However, the introduction of technology in young children's lives is not without controversy, with many public debates about the possible detrimental effect on children's learning (Glauert & Mances, 2013). Although contradictory results have been found concerning the educational effectiveness of CAI games (Randel, Morris, Wetzel, & Whithall, 1992; Kroesbergen & Van Luit, 2003), several studies revealed CAI could be effective as an arithmetic support (Butterworth & Laurillard 2010; Räsänen et al.,2009). Wilson et al., (2006) developed the 'Number Race' for children aged 4 to 8; this open source game (freely available from http://sourceforge.net/projects/numberrace/) is based on the idea that number skills develop from approximate representations of magnitudes. These representations are connected to numbers with the aid of counting. The software trains children by presenting problems adapted to the performance level of the individual child. Children play games with all number formats (concrete sets, digits and number words), practice counting with numbers 1-40 and do additions and subtractions in the range 1-10. Playing the computer game during 5 weeks (4 days a week, sessions of 30 minutes) enhanced number comparison skills in grade 1 of elementary school. Comparing their pretest scores, the children improved and had also better counting skills after the training. The study by Brankaer et al. (2010) tried to replicate Wilson's study with training during four weeks (4 sessions of 10 minutes a week) including a control group. They did not find significant differences between the experimental and control group. Räsänen et al., (2009) also used the 'Number Race' during 3 weeks (10-15 minutes each day). They did find improvements in number comparison tasks.

In addition, Räsänen et al. (2009) documented enhancement in number comparison with their ‘Graphogame–Math’ program used during 3 weeks (during 10-15 minutes each day) to learn the link between a number word and an Arabic number. This ‘Graphogame-Math’ game (openly downloadable from www.lukimat.fi) is based on the idea that learning the correspondences between small sets of objects and numbers helps the child to discover the relationships in the number system and arithmetic. According to Räsänen et al., (2009) the key difference between the ‘Number Race’ and ‘Graphogame-Math’ is that while the ‘Number Race’ stresses the importance of approximate comparison process, the ‘Graphogame-Math’ concentrates solely on exact numerosities and number symbols in the approach to numerical learning. The ‘Number Race’ game starts with the comparison of random dot patterns with large numerical difference, and the solution process does not require verbal mediation. The ‘Graphogame-Math’ starts with small sets of organised dot patterns, which are numerically close to each other, and the comparison process requires exact knowledge of the target quantity and its correspondence with the verbal label (Räsänen et al., 2009).

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

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

The present study

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

<Insert Table 1 here>

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

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

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

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

Method

Participants

Participants were 132 (53% male) full-day kindergartners with a mean age of 68 months (*SD* = 4.01) from five schools in the same school district in Zele (Belgium). We obtained written parental consent for all children to participate in the study. The children had an average intelligence (TIQ = 101.39 (*SD* =12.73), VIQ = 102.9 (*SD* =11.97), PIQ = 99.3 (*SD* =11.68) on the WPPSI. We calculated the Four Factor Index of Social Status (Hollinghead, 1975; Reynders et al., 2005) of the parents. Education and occupation scores were weighted and became a single score for each parent (range 13 to 66). Most parents had working and middle-class-socio-economic backgrounds. Dutch was the only language spoken at home.

Measures

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

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

Wave 1: pretest measures (assessed in kindergarten)

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

Procedural knowledge of counting (see Table 2) was assessed with the TEDI-MATH using accuracy in counting numbers, counting forward to an upper bound (e.g. 'count up to 6'), counting forward from a lower bound (e.g. 'count from 3'), counting forward with an upper and lower bound (e.g. 'count from 5 up to 9'). One point was given for a correct answer. The internal consistency of this task was good (Cronbach's alpha = .73).

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

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

All children were also tested on their mapping skills (as an independent measure) with a number-to-position horizontal number line estimation task. This Number Line Estimation (NLE) task used a 0-100 interval, in line with Berteletti and colleagues (2010) and Booth and Siegler (2006). The task included three exercise trials and 30 test trials presented in three different formats; as Arabic numerals (e.g. anchors 0 and 100, target number 25), spoken number words (e.g. anchors zero and hundred, target number twenty-five), and dot patterns (e.g. anchors of zero dots and hundred dots, target number twenty-five dots). The dot patterns were controlled for perceptual variables using the procedure by Dehaene, Izard and Piazza (2005), meaning that in half the trials, the dot size was constant, and in the other half, the size of the total occupied area of the dots was constant. The number line had a lower and upper anchor, but no periodically marked scale. No feedback was given to participants regarding the accuracy of their marks. The Percentage Absolute Error (PAE) was calculated per child as a measure of children’s mapping skills, following a formula by Siegler and Booth (2004).

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

Wave 2: posttest measure (assessed in kindergarten)

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

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

In grade 1 (wave 3), all children completed the 0-100 number line estimation task and the Kortrijk Arithmetic Test Revised(Kortrijkse Rekentest Revision, KRT-R, Baudonck et al., 2006). The Kortrijk Arithmetic Test Revision (Kortrijkse Rekentest Revision, KRT-R; Baudonck et al., 2006) is a standardised test of arithmetical achievement which requires children to solve 30 mental arithmetic (e.g. '16-12 =_') and 30 number knowledge tasks (e.g. '1 more than 3 is _'). The KRT-R is frequently used in Flemish education as a measure of arithmetic achievement. The psychometric value of the KRT-R has been demonstrated on a sample of 3,246 children. A validity coefficient (correlation with school results) and reliability coefficient (Cronbach's alpha) of .50 and .92 respectively were found for first grade.

Procedure

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

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

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

Throughout the interventions and across paraprofessionals, treatment integrity was very high and there was a 100% fidelity to essential instruction practices.

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

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

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

Results

Preliminary comparisons (wave 1)

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

<Insert Table 2 here>

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

In order to investigate the research hypotheses on the modifiability of early numerical skills (hypothesis 1), as well as on the value of counting versus number comparison, we included instruction on learning arithmetic skills (hypothesis 2), a posttest (wave 2) and a delayed posttest (wave 3). Dependent measures were analyzed by an univariate analysis of variance (ANOVA) or multivariate analysis of conditional variance (MANOVA) (counting CAI, number comparison CAI, control condition) as a group. Each (M)ANOVA determined whether there was a significance in the three conditions, when compared to the dependent measure at pretesting, posttesting and delayed posttesting. In addition, posthoc tests were performed on the posttest and delayed posttest scores using an appropriate posthoc procedure (using Tukey if equal variance could be assumed from the Levene test and Tamhane if equal variance could not be assumed from the Levene test). In addition, we calculated the observed power and effect sizes.

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

In addition, the MANOVA using number knowledge and mental arithmetic assessed in grade 1 (wave 3), as dependent variable, was significant on the multivariate level (F (4, 250) = 4.03; p =.003; $\eta^2 = .06$). Significant differences were found between the groups for number knowledge (F (2,125) = 6.42; p =.002, $\eta^2 = .09$)

and mental arithmetic (*F* (2, 125) = 6.16; *p* = .003; η^2 = .09). Table 3 provides *M*, *SD* and posthoc analyses between the groups.

<Insert Table 3 here>

Both CAI groups had a better number knowledge compared to the control group. There was a significant difference between the CAI on counting and the control group for mental arithmetic.

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

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

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

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

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

As expected, children did not differ on mapping skills (*F* (2, 127) = 0.83; *p* = .436) before the intervention (in wave 1). However, after the CAI (in wave 3), the three groups did not differ significantly on mapping performances either (*F* (2, 119) = 0.61; *p* = .547), meaning that the CAI did not enhance mapping skills. Table 4 provides raw score means and standard deviations for the Percentage of Absolute

Error (PAE) on the 0-100 number line estimation task which was separated into pretest (wave 1) and delayed posttest (wave 3).

<Insert Table 4 here>

Discussion

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

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

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

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

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

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

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

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

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

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Table 1
Different 'serious games' compared

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

Table 2
Means and Standard Deviations of the pretest skills in kindergarten

	Control group	Counting games	Comparison games	*F*
	N= 49	*N*=44	*N*=39	(2, 129)=.
Mean age	67.67 *(4.05)*	68.50 *(3.83)*	68.28 *(3.96)*	0.58
SES father	37.74 *(10.18)*	34.48 *(12.56)*	38,21 *(11,19)*	1.06
SES mother	38.55 *(11.08)*	38.67 *(11.29)*	41,18 *(10,58)*	0.01
VIQ	101.57 *(11.11)*	102.50 *(12.68)*	103,67 *(12,42)*	0.31
PIQ	96.86 *(12.83)*	99.41 *(10.10)*	101.72 *(11.79)*	1.90
Procedural Counting	6.31 *(1.58)*	6.30 *(1.74)*	6.49 *(1.71)*	0.17
Conceptual Counting	9.98 *(3.07)*	9.75 *(3.38)*	10,41 *(2.31)*	0.52
Arithmetic (wave 1)	7.39 *(5.16)*	7.55 *(5.55)*	7.64 *(4.94)*	0.03

$^{*}p \leq 05$

Table 3
Arithmetic skills in kindergarten and grade 1

	Control group M *(SD)*	Counting games M *(SD)*	Comparison games M *(SD)*	
Posttest (wave 2) Arithmetic	8.65(*c*) *(3.38)*	12.85(*a*) *(3.12)*	10.86(*b*) *(3.12)*	F (2, 129) = 19.70*
Delayed test (wave 3) Number knowledge	19.22(*b*) *(5.94)*	22.58(*a*) *(4.28)*	22.34(*a*) *(4.40)*	F (2, 125) = 6.42*
Delayed test (wave 3) Mental Arithmetic	18.11(*b*) *(6.60)*	22.30(*a*) *(4.98)*	20.66 *(5.40)*	F (2, 125) = 6.16*

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

Table 4
Mapping skills separated by pretest and delayed posttest (Grade 1).

	Control group M *(SD)*	Counting games M *(SD)*	Comparison games M *(SD)*	
Pretest (wave 1) PAE	*25.22 (9.14)*	*25.98 (8.96)*	*23.51 (7.77)*	F (2, 129) = 0.86
Delayed test (wave 3) PAE	*16.64 (6.73)*	*18.29 (8.05)*	*18.15 (7.44)*	F (2, 125) = 0.68

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