

Cognition and Neurosciences

Training counting skills and working memory in preschool

MINNA KYTTÄLÄ,¹ KAISA KANERVA² and EVELYN KROESBERGEN³

¹University of Turku, Finland

²University of Helsinki, Finland

³Utrecht University, The Netherlands

Kyttälä, M., Kanerva, K. & Kroesbergen, E. (2015). Training counting skills and working memory in preschool. *Scandinavian Journal of Psychology*, 56, 363–370.

Previous studies have shown that early numeracy skills predict later mathematics learning and that they can be improved by training. Cognitive abilities, especially working memory (WM), play an important role in early numeracy, as well. Several studies have shown that working memory is related to early numeracy. So far, existing literature offers a good few examples of studies in which WM training has led to improvements in early numerical performance as well. In this study, we aim at investigating the effects of two different training conditions: (1) counting training; and (2) simultaneous training of WM and counting on five- to six-year-old preschoolers' (N = 61) counting skills. The results show that domain-specific training in mathematical skills is more effective in improving early numerical performance than WM and counting training combined. Based on our results, preschool-aged children do not seem to benefit from short period group training of WM skills. However, because of several intervening factors, one should not conclude that young children's WM training is ineffectual. Instead, future studies should be conducted to further investigate the issue.

Key words: Working memory, working memory training, early numeracy, counting skills, preschool.

Minna Kyttälä, Department of Teacher Education, University of Turku, Assistentinkatu 5, Turun Yliopisto, FI 20014, Finland.

E-mail: minna.kyttala@utu.fi.

INTRODUCTION

In the preschool and kindergarten years, significant differences between children's numerical skills can be observed, and those early numeracy skills also predict mathematics development and performance later (Aunola, Leskinen, Lerkkanen & Nurmi, 2004; Duncan, Dowsett, Claessens *et al.*, 2007; Geary, 2007; Geary, Hoard, Nugent & Bailey, 2013; Toll, Van der Ven, Kroesbergen & Van Luit, 2011). However, even as prior mathematical skills seem to have a significant role in determining later performance, these skills can be improved by systematic training even before formal schooling (Kroesbergen & Van Luit, 2003). The development of early numeracy skills and the performance in early numeracy tasks is supported by different cognitive systems. One of those supporting systems is working memory, which refers to the individual's limited-capacity information processing system capable of storing and manipulating information during a range of cognitive tasks. Recent studies show that WM competence measured at preschool age does not only predict mathematical performance during preschool years (Kroesbergen, Van Luit, Naglieri, Franchi & Taddei, 2010; Kyttälä, Aunio & Hautamäki, 2010; Kyttälä, Aunio, Lehto, Van Luit & Hautamäki, 2003), but also development of basic arithmetic skills and use of arithmetic strategies during early school years (Krajewski & Schneider, 2009). Similarly to early numeracy, WM skills also seem to be modifiable. So far, existing literature offers a good few examples of studies in which WM training has led to improvements in mathematical performance as well (Holmes, Gathercole & Dunning, 2009; Kroesbergen, Van't Noordende & Kolkman, 2012, 2014; Passolunghi & Costa, 2014). In this study, we compare the effects of two different training conditions in preschool children: (1) counting training; and (2) simultaneous training of WM and counting on early numeracy.

EARLY NUMERACY SKILLS ARE IMPORTANT FOR LATER MATHEMATICAL PROGRESS

Children's mathematical skills begin to develop even before receiving formal mathematics education in elementary school (Jordan, Kaplan, Oláh & Locuniak, 2006; Van de Rijt & Van Luit, 1999). These early numeracy skills include 'Piagetian' tasks (i.e., conservation, classification, correspondation and seriation) as well as counting skills (Van de Rijt & Van Luit, 1999). According to Von Aster and Shalev (2007), number sense develops from subitizing through verbal counting and understanding of digits to the use of a mental number line. In kindergarten, the ability to count and to use counting to determine exact quantities is considered to be a fundamental numerical ability (Gallistel & Gelman, 1992). Counting consists of several aspects, namely the use of number words (counting forwards and backwards, using cardinal and ordinal numbers); structured counting (counting while pointing to objects); and resultative counting (understanding and applying the cardinal principle of counting) (Van de Rijt & Van Luit, 1999).

Early math trajectories have indeed been found to predict math achievement in the first school years fairly well. Early numeracy skills in the beginning of kindergarten have been found to predict mathematical performance both in first grade (Jordan, Kaplan, Locuniak & Ramineni, 2007) and in second grade (Locuniak & Jordan, 2008). In accordance with this, Geary, Hoard and Hamson (1999) found that children who score low on a counting task also score low on later mathematics. Early numeracy skills are necessary for success in mathematics (Aunio, Hautamäki & Van Luit, 2005; Aunio & Niemivirta, 2010). Therefore, it is important to intervene when children have insufficient early numeracy skills.

Former research has shown that early numeracy skills can be trained, both with normally developing children and with children at risk of mathematical difficulties (e.g., Van de Rijt & Van Luit,

1998; Toll & Van Luit, 2012). However, the transfer effects to later formal math skills are generally small, especially for children at risk for math learning difficulties. Recent research, however, has shown promising results in improving early numeracy by playing numerical games (Ramani & Siegler, 2008; Siegler & Ramani, 2008; Whyte & Bull, 2008). Siegler and Ramani (2008) conducted an experiment with 4-year-old children from low-income families. The studied group played a linear board game with squares labelled from 1 to 10 during four 15-minute sessions within two weeks. Large effects on children's early numeracy were observed (Siegler & Ramani, 2008). Ramani and Siegler (2008) conducted a second experiment and the same findings resulted. Not only number line estimation, but also counting, numerical magnitude comparison and numeral identification were assessed. It was found that the children who had played the linear numerical board game showed improvement in these additional tasks too (Ramani & Siegler, 2008).

In a recent study, the effect of early mathematical intervention on low and high achieving children's early numeracy skills was studied (Toll & van Luit, 2013). In this study, both low and high performing children progressed in early numeracy over the course of the study. The results indicated specifically that, as a result of the intervention, children with higher verbal working memory resources developed more in early numeracy skills than children with lower verbal working memory. These results indicate that cognitive factors underlying early numeracy skills, such as the working memory, have an impact in how children profit from training.

WORKING MEMORY AND EARLY NUMERACY

Low numeracy skills can be caused by the lack of experience with numbers and number related activities, and this is supported by research on mathematical skills of children from low-income families (Siegler & Ramani, 2008; Tudge & Doucet, 2004). However, lack of experience is not the only cause of low mathematical skills in children. Cognitive abilities, especially working memory, play an important role in mathematics as well. Several studies have pointed out that working memory is related to early numeracy skills (e.g., Locuniak & Jordan, 2008; Noël, 2009; Passolunghi & Lanfranchi, 2012; Preßler, Krajewski & Hasselhorn, 2013; Rasmussen & Bisanz, 2005). Therefore, this study will explore the enhancement of early numeracy skills in relation to the enhancement of working memory skills.

In this study, the tripartite working memory model, originally developed by Baddeley and Hitch (1974) and then extended by Baddeley (2000), was used as a WM framework. It is the most frequently used model to explain WM in studies concerning WM and mathematics (e.g., Alloway, Gathercole, Willis & Adams, 2004; Bull, Espy & Wiebe, 2008; Kroesbergen, Van de Rijt & Van Luit, 2007; Rasmussen & Bisanz, 2005). The model includes both passive, modality-specific storage functions (short-term memory) and active processing functions. According to Baddeley (1986, 1997), WM is comprised of an active processing and supervising system, the central executive (CE), and two modality-specific storage units: the phonological loop (PL) and the visuo-spatial sketchpad (VSSP). Baddeley (2000) later extended the original model with a new component, a

domain-free episodic buffer, which is supposed to integrate information from the two slave systems and long-term memory (LTM).

Poor working memory skills seem to be related to early numeracy (Bull & Scerif, 2001; Espy, McDiarmid, Cwik, Stalets, Hambry & Senn, 2004; Friso-Van de Bos, Kolkman, Kroesbergen & Leseman, 2014; Noël, 2009; Rasmussen & Bisanz, 2005). Young children that are at risk for mathematical difficulties have poorer WM skills than children who perform on average level (Kyttälä *et al.*, 2010). Poor WM resources seem to constrain the acquisition of basic academic skills during the first school years, as well (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; De Smedt, Janssen, Bouwens, Verschaffel, Boets & Ghesquière, 2009; Gathercole, Tiffany, Briscoe, Thorn & ALSPAC team, 2005; Passolunghi, Vercelloni & Schadee, 2007). Several studies have also found evidence showing the involvement of WM in mathematical performance during children's later school years, even in early adolescence (e.g., Friso-Van den Bos, Van der Ven, Kroesbergen & Van Luit, 2013; Hitch, 1978; Holmes & Adams, 2006; Kyttälä, 2008; Kyttälä & Lehto, 2008; Reuhkala, 2001; Wilson & Swanson, 2001). Thus, poor working memory resources seem to be related to poor mathematical performance already early in life.

WORKING MEMORY – A MODIFIABLE RESOURCE?

Based on recent results, WM skills seem to be related to early numeracy. Thus, it seems that WM is one of the cognitive factors behind numerical performance. A key question is, whether WM is a fixed trait or a modifiable resource. So far we know that WM capacity increases quite rapidly during the childhood years (Logie & Pearson, 1997; Siegel, 1994; Wilson, Scott & Power, 1987), but that there are significant individual differences in WM capacities between children (Kyttälä *et al.*, 2010). Some studies with older children, adolescents and adults have shown that training improves WM performance, at least in tasks that resemble the trained tasks (Harrison, Shipstead, Hicks, Hambrick, Redick & Engle, 2014). Functional MRI-studies included in WM training have shown evidence of plasticity in neural systems underlying working memory (Olesen, Westerberg & Klingberg, 2004; Westerberg & Klingberg, 2007) indicating a typical skill-learning pattern. The promising results have led to extensive studying of WM training in different populations. However, currently the produced transfer effects following WM training are under a heated debate. A large meta-analysis of Melby-Lervåg and Hulme (2013) suggests that WM training mainly produces training effects that cannot be generalized. Justified methodological concerns have also been raised regarding existing studies (Shipstead, Redick & Engle, 2012). According to Shipstead *et al.* (2012), in most of the studies concentrating on effects of WM training, positive effects can be explained by task-specific training resulting from WM tasks that excessively resemble the training tasks. Thus, studies with broader variety of WM tasks are needed. Nevertheless, the evidence of malleability of working memory skills in consequence of WM training validates the interest in investigating if not only pure numerical training, but also numerical training which requires working memory resources that have effects on children's early numeracy.

Additionally, there is strong need for more educationally oriented studies of the practical possibilities for training early numeracy and developing intervention instruments for preschool, kindergarten and school practices. In order to develop more effective ways to teach, we need information not only about the mathematical skills and cognitive resources of those children who have mathematical difficulties, but also about intervention methods that are effective in practical settings, for example in preschool or kindergarten. As previous results (Kyttälä *et al.*, 2010) show, differences in early numeracy skills between children with and without mathematical difficulties could not be explained solely by the abstract concept 'fluid intelligence' or by poor numerical skills. Instead, poor performance in early numeracy before formal schooling appears to be related to information storing and processing deficits to varying degrees, and this should be taken into account while planning classroom activities and new teaching and intervention methods.

CURRENT STUDY

Previous studies have shown that preschool mathematical skills predict later mathematics learning (Aunola *et al.*, 2004; Duncan *et al.*, 2007). Thus, the better the early numeracy skills are at the beginning of formal mathematics education, the easier it is for a child to learn formal mathematics. As Aunola *et al.* (2004) observed, during the first school years the growth of mathematical competence is fastest among children who had good mathematical skills already before formal schooling. Previous results also show that children who start preschool with poor early numeracy do not seem to benefit from preschool education as much as children with better baseline skills (Claessens, Duncan & Engel, 2009). However, even though prior mathematical skills seem to have a significant role in determining later performance, it is possible to improve them by systematic training even before formal schooling. Previous studies suggest that mathematics skills can be trained with domain-specific interventions (Kroesbergen & Van Luit, 2003). Considering that early numeracy skills predict subsequent mathematical performance during school years, it seems relevant to improve early numeracy skills of risk group children prior to school to prevent learning difficulties.

However, previous results show that children, who have poor early numeracy before formal mathematics education, start the school not only with poor numerical skills but also with poor supporting competencies, including WM (Kyttälä *et al.*, 2010). Poor WM resources seem to be related to poor performance in mathematics also during later school years (Kyttälä, 2008; Kyttälä & Lehto, 2008; Reuhkala, 2001). If WM is such an important cognitive function behind mathematical performance, it could be assumed that improving working memory also leads to better mathematics performance. So far, existing literature offers a good few examples of studies in which WM training has led to improvements in mathematical performance as well (Holmes *et al.* 2009; Kroesbergen *et al.*, 2012, 2014). Based on their results, Kroesbergen *et al.* (2014) hypothesized that WM training with numerical tasks was more effective in improving early numeracy skills than WM training using non-numerical tasks. In

other words, their results suggested that the type of materials used in WM training matter.

In this study, we aim at investigating the effects of two different training conditions that have proven to be effective in previous studies: (1) counting training (i.e., domain-specific numerical training); and (2) simultaneous training of WM and counting (i.e., domain-specific numerical training combined with domain-general WM training) in enhancing early numerical skills. More specifically, we target to investigate whether the pre-test/post-test change in two experimental groups differ from the change in the control group, and whether the pre-test/post-test change in the same two experimental groups differ from each other in counting skills. Based on previous studies, we hypothesize that both intervention groups should perform better than the control group after the intervention.

With few exceptions, we use the same intervention programs as were used by Kroesbergen *et al.* (2012; experiment 2) in order to investigate whether similar effects can be observed in another context. Instead of training counting skills or both counting and WM skills of low-performing children like in the study of Kroesbergen *et al.* (2012), our target group consists of children at varying performance levels, that is, typical Finnish preschool children. Considering the increasing debate of the methodological problems in WM training studies (see e.g. Melby-Lervåg & Hulme, 2013; Shipstead *et al.*, 2012), replications of existing studies showing positive short and long-term transfer effects are needed. Interventions used in our study are especially suitable for preschool and kindergarten settings, because they are performed in small groups and integrated to plays that children of this age group are interested in.

METHODS

Participants

The participants in the study were 61 Finnish children (29 girls) from nine metropolitan preschools. At the time of the pre-tests, the children were about five to six years old (Mean age = 5.9 years; *SD* = 8.6 months) preschoolers and about to start kindergarten in three months. In Finland, kindergarten begins in August, the year the child becomes six years old; compulsory schooling starts in August the year a child becomes seven years old.

Experimental design

The participating children were divided into three different experimental groups: G_1 (counting training; $N = 21$), G_2 (WM and counting training; $N = 23$) and G_{controls} group (age-matched control group; $N = 17$) based on their age, gender and preschool. The distribution of boys and girls in the three groups could be considered equal, $\chi^2(2, N = 61) = 4.90$, $p = 0.09$. The three experimental groups did not differ from one another in age, $F(2,58) = 0.217$, $p = 0.81$). The interventions were conducted in small groups (4–7 children). Children from the same preschool were included in the same intervention or control group except in two larger preschools in which there were two different groups.

The pre-tests were conducted within a two-week span. The children were tested individually, by a trained research assistant. The intervention lasted for four weeks. There were two intervention sessions per week, each lasting 30 minutes. The post-tests were conducted within one week after the four-week intervention.

Pre- and post-test instruments: counting skills

Early numeracy test. Children's counting skills were measured by using the counting subscale from the Early Numeracy Test (Van Luit, Van de Rijt & Aunio, 2006). The target group for the test was children from four to seven years old. Three subscales of version A were used: (1) use of number words (counting forwards and backwards up to 20, using cardinal and ordinal numbers); (2) structured counting (counting while pointing to objects, recognizing numbers on a die); and (3) resultative counting (counting without pointing to objects). Each of the three subscales contained five items. The test was given individually and the counting subscale took about 15 minutes for a child to complete. The 15 items were scored by giving one point for the correct answer and zero for a wrong answer (e.g., Van de Rijt, Van Luit & Pennings, 1999). The children were not given feedback as to whether their response was correct or incorrect, neither was the test situation timed. Cronbach's alpha for this sample in pre-test was 0.75, and in post-test 0.80.

Pre- and post-test instruments: working memory

Matrix task. This was created for a previous study with young children (Kyttälä et al., 2003), but the original idea was based on the tasks created by Wilson et al. (1987). The task was expected to probe visual aspects of non-verbal working memory, and it was used to assess passive, short-term storage of simultaneous visuo-spatial information. The participants were presented with matrix patterns on paper cards. In each matrix pattern, half the squares were marked with a black dot and half the squares were empty. Each child was asked to recall which squares had black dots and point to them on an empty answer matrix pattern. For each pattern size there were three items, and in every fourth pattern the pattern size increased by two squares. The smallest patterns comprised four squares, and the task ended when the participant recalled two out of three patterns in a certain pattern size incorrectly. The maximum score was 15. Cronbach's alpha for this sample was 0.80 at pre-test phase, and 0.74 at the post-test phase.

The odd-one-out test. This test was used to measure the non-verbal CE of young children. The task was based on a procedure used, for instance, by Henry and MacLean (2003) and Jarvis and Gathercole (2003) to measure visuo-spatial CE resources. The children were shown a rectangular card divided into three same-sized boxes (Fig. 1). There was a geometrical shape in each box. On every card, two shapes were the same and one was different. The child's task was to point to the shape that differed from the others and simultaneously remember in which box the different shape was exactly. The child was simultaneously given a stimulus card showing the figures and a blank response sheet with blank boxes under the stimulus card. When the child pointed at the figure identified as different from the others, the experimenter placed her finger on the same box on the response sheet and said: 'The different shape is in this box. Try to keep in mind where the odd one out is hiding.'

The test began with a sequence of two stimulus cards. The child was presented with one stimulus card and asked to point to the odd-one-out, while keeping in mind the place where the odd-one-out was. The stimulus card was removed and replaced with another stimulus card. Again the child was asked to point to the odd-one-out and remember its place. After the sequence the child was asked to point to the places where the differing shapes had been. On every response sheet there were as many blank response boxes as there were stimulus cards. The response sheets were covered up during the presentation of the stimulus cards to prevent the

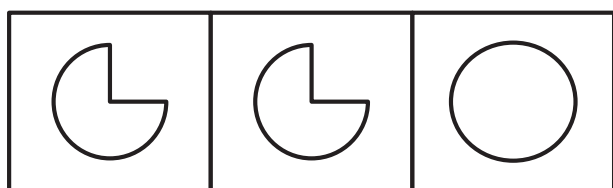


Fig. 1. Example item of the odd-one-out test.

children marking the positions of the odd-ones-out with their fingers. There were three trials within every sequence. The sequence length varied from two to four. The total score was the number of correctly recalled sequences. The maximum score was nine. Cronbach's alpha for this sample for pre-test phase was 0.79 and for post-test phase 0.76.

Word-span forward task. This task was used to measure PL. The task has been widely used (see e.g., Baddeley, 1986). In this experiment, two-syllable, common Finnish nouns are introduced to the participants. The four-letter-long words were spoken aloud. During the task, each word was used only once. The words were presented in sets, starting with two nouns in a same set toward the maximum level of five nouns in a same set. There were four sets in each degree of difficulty. After each set, the participant was supposed to say the presented words aloud in their correct serial order. The task ended when the participant failed to recall three out of four sets at a certain degree of difficulty. The Cronbach's alpha for this sample for the pre-test was 0.76 and for the post-test 0.67.

Word-span backwards task. This was used to measure mainly verbal CE function of WM (see, e.g., Gathercole, Brown & Pickering, 2003; Jarvis & Gathercole, 2003). The procedure was similar to word-span task with the exception that in this task the participant had to recall the presented words in reverse order. The test began with a sequence of two words, and it ended when the participant recalled two out of the four trials for a certain sequence incorrectly. The maximum sequence length was four words. The Cronbach's alpha for this sample was at the pre-test phase was 0.57 and for the post-test 0.56.

Digit-span forward task. This task was used to measure PL. The digit-span was presented and scored as recommended in the WISC-III Manual (Wechsler, 2010). In the digit-span forward task the participant was required to recall a list of digits (1–9) in a correct order. The digits were spoken by the experimenter at a rate of one per second. The lists were presented in ascending order, two lists in each set, starting from lists of two digits and continuing to lists of nine digits. The task was continued until the participant made a mistake in both of the two lists of a set. The maximum raw score for digit-span forward is 16. Cronbach's alpha at the pre-test phase was 0.55, and at the post-test phase 0.45.

Digit-span backward task. The Digit-span backward task was used to measure verbal WM functions of WM. The digit-span backwards subtask from the WISC-III (Wechsler, 2010) was used. The task was conducted similarly as the digit-span forward, except that the participant was required to recall the digits in reverse order from what was presented, and the maximum list length was eight. The task was continued until the participant made a mistake in both of the two lists in a set. The maximum raw score is 14. Cronbach's alpha at the pre-test phase was 0.60 and at the post-test phase 0.64.

Crystallized intelligence

Block design and vocabulary. These are the two subtests of WISC-III (Wechsler, 2010) that were adopted for assessing crystallized intelligence in the pre-test phase. These subtests were selected because they have high reliability and high correlation with the full scale IQ (Silverstein, 1982). Block design assesses the abilities of nonverbal conceptual formation. The vocabulary subtest assesses knowledge about words.

Training

Counting training. In the first week of the training, digits from 1 to 10 were used in all training activities. Children practiced counting from 1 to 10 (number word sequence; forward, backward), played a bingo game in which they practiced connecting number symbols with the same amount of dots, and finally practiced number word sequence by walking on a digit path. In the second week of the training, the digits from 1 to 20 were used. The children practiced counting from 1 to 20 (forward, backwards), made a right sequence of paper digits from 1 to 20, and played a simple

board game with a dice (1–3). In the third week of the training, the numbers from 1 to 20, 1 to 50 and 1 to 100 were used. The children counted backwards from 20, from 1 to 50 and from 1 to 100 using only whole tens (10, 20, 30...100). They also played a game in which they had to compare number symbols and a set of dots. Finally, they played a simple board game (digits 1 to 100). In the last week, digits 1 to 100 were practiced. Children practiced counting from 1 to 100. They also estimated the location of digits on an empty number line and played a simple board game with a dice.

WM and counting training. In the first week of the training, the numbers from 1 to 10 were practiced. The children played a game, in which they had to remember things that they could bring on a holiday, and how many they could bring, for example: 'I go on a holiday and I take one toothbrush with me.' The number of different items and their counts increased after every child's turn. The children also played a memory game in which they had to find right pairs by finding a certain card with a number symbol on it and a card with corresponding amount of dots. Finally, the children played a board game (1–10) with a dice. Each child threw a dice and said aloud which number they got. They were all told to remember each other's numbers and after every child had thrown the dice, one of the children was asked to say what number each child threw. Then each child moved the right amount of steps on his/her own game board. In the second week, children played the same games as during the first week, with the exception that in the second week digits from 1 to 20 were used. In the third week, the children played a game, in which they had to remember which animals they would see in a zoo, and how many of those animals they would see, for example: 'I go to the zoo and see five elephants and two tigers.' The number of different animals and their counts increased after every child's turn. The second game was a sorting game, in which two cards were presented repeatedly: one with a red number, and one with the same number in blue. The children had to sort the cards by color and after that remember which numbers were on the cards. Finally, the children played the same board game containing digits 1 to 20 as during the previous week. In the last week, children played the Zoo-game. After that, they played a memory game with digits 1 to 20, and finally the same sorting game as during the previous week.

Data-analysis

First, to check potential pre-intervention differences between the two experimental groups (G_1 and G_2) and the control group (G_{controls}), one-way ANOVAs comparing the performance in pre-assessments were calculated. Second, a series of repeated measures ANOVAs was conducted to test whether the counting skills (total score and subtotals)

development between the pre-test and post-test stages differed between the three groups. Based on our prior hypotheses, planned comparisons comparing counting performance of the two intervention groups with the control group were also performed. Third, in order to investigate the effect of WM training on WM performance, repeated measures ANOVAs comparing WM performance between the pre-test and post-test phase in all three groups were performed. When reporting results of planned comparisons, both exact p -values (p) and Sidak corrected (p_{SID}) p -values are reported. All participants were included in the analysis, and there were no missing values in the data. No other experimental conditions were conducted and no other measures were adopted in this study except the reported.

RESULTS

The means and standard deviations for two experimental groups and the control group are presented in Table 1. At the pre-test phase, the three experimental groups performed equally in counting tasks, WM tasks and intelligence tasks. The groups did not differ from one another in counting skills (total score; $F[2,58] = 2.10$, $p = 0.13$; $\eta^2 = 0.07$) or in two crystallized intelligence scores (Block Design ($F[2, 58] = 0.03$, $p = 0.97$; $\eta^2 = 0.00$); Vocabulary ($F[2, 58] = 0.03$, $p = 0.97$; $\eta^2 = 0.00$). Neither did the three groups differ in Matrix task ($F[2, 58] = 0.15$, $p = 0.86$ $\eta^2 = 0.01$), Odd-One-out ($F[2, 58] = 2.97$, $p = 0.06$; $\eta^2 = 0.09$), Word Span Forward ($F[2, 58] = 0.47$, $p = 0.63$; $\eta^2 = 0.02$), Word Span Backwards ($F[2, 58] = 0.66$, $p = 0.52$; $\eta^2 = 0.02$), Digit Span ($F[2, 58] = 0.90$, $p = 0.41$ $\eta^2 = 0.03$) or Digit Span Backwards ($F[2, 58] = 0.45$, $p = 0.64$; $\eta^2 = 0.02$).

We investigated the effectiveness of interventions by calculating a series of repeated measures ANOVAs (omnibus F -test) between pre- and post-test scores for the Early Numeracy Test in order to compare the change in time in the three groups (Table 1). As to performance in the Early Numeracy Test (Total Score), our results showed a significant time \times intervention interaction. Planned pairwise comparisons showed that the performance gain in Early Numeracy Test in the G_1 was significantly larger than in the G_{controls} ($F[1,58] = 4.21$, $p = 0.04$, $p_{\text{SID}} = 0.13$; $\eta^2 = 0.07$). However, the Sidak corrected p -value was not significant as it indicated a slightly rising risk for type I error. In addition, the gain was significantly larger in the G_1 than

Table 1. The pre- and post-assessment scores (mean and SD) in mathematics and working memory tasks

	Counting group		WM and counting group		Control group		<i>F</i>	<i>η</i> ²
	Pre	Post	Pre	Post	Pre	Post		
Early numeracy test								
Use of num. words	3.57 (1.57)	4.33 (0.86)	3.30 (1.46)	3.87 (1.39)	2.71 (1.79)	3.47 (1.62)	0.19	0.01
Structured counting	2.57 (0.98)	3.66 (1.20)	3.26 (1.18)	3.65 (1.11)	2.29 (1.36)	2.88 (1.27)	1.56	0.05
Resultative counting	2.48 (1.21)	3.19 (0.87)	2.65 (1.23)	2.70 (1.29)	2.12 (1.50)	1.94 (1.30)	2.82	0.09
Total	8.62 (3.07)	11.19 (2.32)	9.22 (2.98)	10.17 (2.93)	7.18 (3.45)	8.29 (3.37)	3.51*	0.11
Working memory tasks								
Matrix	6.05 (2.64)	6.67 (2.83)	6.22 (2.83)	6.70 (3.28)	5.71 (3.31)	6.59 (3.78)	0.17	0.01
Odd-one-out	5.19 (3.01)	7.57 (2.75)	7.26 (2.65)	8.17 (1.95)	6.82 (3.17)	7.47 (3.00)	1.73	0.06
Word-span	10.81 (1.86)	11.00 (2.07)	10.22 (1.93)	10.09 (1.78)	10.47 (2.32)	11.00 (2.26)	0.89	0.03
Word-span backwards	4.67 (1.39)	4.52 (1.17)	5.22 (1.70)	5.30 (1.33)	5.00 (1.70)	4.76 (1.44)	0.26	0.01
Digit-span	5.43 (1.21)	5.38 (1.28)	5.48 (1.41)	5.26 (1.05)	4.94 (0.90)	5.35 (0.93)	1.79	0.06
Digit-span backwards	2.67 (0.86)	2.71 (0.78)	2.48 (0.90)	2.35 (0.71)	2.41 (0.87)	2.35 (1.11)	0.18	0.01

Notes: F and effect size are for time \times group interaction.

*the interaction is statistically significant. $p < 0.05$.

in the G_2 ($F[1,58] = 6.06$, $p = 0.02$, $p_{SID} = 0.05$; $\eta^2 = 0.10$). This time, the Sidak corrected p -value remained statistically significant as well. The gain in the G_2 did not differ from the $G_{controls}$ ($F[1,58] = 0.05$, $p = 0.82$, $p_{SID} = 0.99$). This result shows that the Counting Group scores in Early Numeracy Test increased due to training, while the Control Group or the WM and Counting Group did not show such a pattern as a function of time.

As to performance in the subtests of the Early Numeracy Test (Use of Number Words, Structured Counting, and Resultative Counting), our results showed no significant time \times intervention interaction (Table 1). Since significant omnibus F -test is not a prerequisite for planned comparisons (Rutherford, 2001), and since we expected domain-specific counting training to be more effective than control condition and WM and counting training, we continued the analysis with planned comparisons in order to compare G_1 vs. $G_{controls}$ and G_1 vs. G_2 . Planned comparisons are more specific than the omnibus F -test, so they can be done whether or not the overall test is significant. Planned pairwise comparisons showed that the performance gain of the G_1 in Resultative Counting subtest was significantly larger compared to $G_{controls}$ ($F[1,58] = 4.93$, $p = 0.03$, $p_{SID} = 0.09$; $\eta^2 = 0.08$). However, the Sidak corrected p -value was not significant. There were no statistically significant gain in the G_2 compared to $G_{controls}$ ($F[1,58] = 0.31$, $p = 0.58$, $p_{SID} = 0.93$; $\eta^2 = 0.01$) or G_1 compared to G_2 ($F[1,58] = 3.27$, $p = 0.08$, $p_{SID} = 0.21$; $\eta^2 = 0.05$). In other subtests the pairwise comparisons did not show any statistically significant differences between the groups.

For performance in Working Memory tasks, our results did not show significant time \times intervention interaction (Table 1). This means that the change in the Working Memory performance did not differ statistically in the three groups from pre-assessment to post-assessment.

DISCUSSION

The aim of this study was to compare the effects of two different training conditions: (1) counting training; and (2) simultaneous training of WM and counting in improving counting performance by replicating the study of Kroesbergen *et al.* (2012, experiment 2) in another context. Our results showed that domain-specific counting training was superior in improving counting performance to mixed WM-counting training. These results support the results of previous studies (Kroesbergen & Van Luit, 2003; Toll & Van Luit *et al.*, 2012) showing that domain-specific training of mathematical skills is effective, and it is more effective in improving early numerical performance than domain-general training. Our results suggest that even with a short and incomprehensive counting training in preschool context it is quite possible to induce positive effects on preschool-aged children's counting skills.

However, our results also contradict those of Kroesbergen *et al.* (2012, experiment 2). They observed that combined WM and counting training lead to improvements in mathematical performance, as well. Despite the comparable training programs, similar results could not be reached in our study. One potential explanation for these inconsistent results is that the target group differed in these two studies. In the study of Kroesbergen *et al.* (2012), the participating children were at risk for mathematical

difficulties and they had been selected based on their performance in a national preparatory mathematics test using a cut-off criterion of below 25th percentile. In our study, the participating children represent typical Finnish preschool children with different performance levels. In other words, no selection took place. It is possible that low-performing children benefit from combined WM and counting training more than children at higher performance levels.

Even though this combined training of WM and counting had fewer effects on counting performance than domain specific counting training, it is too early to reject WM training as unnecessary. First, it is possible that the positive transfer effects of WM training on counting are not observable immediately after the training but rather later on as the improved WM resources start to support the development of counting skills. Second, it is possible that group WM training is not effective enough to produce large gains after such a short training period (four weeks). Previously, it has been suggested that WM training might be dosage-dependent: the more WM training, the more improvement (Jaeggi, Buschkuhl, Jonides & Perrig, 2008). In group training, it is probable that some participants get more training than others. That is, the amount of training does not reach all the participants equally. Third, another problem in our study was that the group training was not adaptive. Klingberg *et al.* (2010) have gained evidence that WM training should be adaptive to produce training effects. That is, when training WM, cognitive load should be held at the highest possible individual performance level during the training process. In our study, all group members received the same level of training. Fourth, it is possible that when WM training was combined with counting training, the training got too complex or too dispersed to benefit young children. Even if the combined training contained counting, it was possibly too ineffective to produce learning effects. Even if it contained memorizing, it was not potentially significant enough to produce WM effects.

It should also be noted that combined WM and counting training did not induce WM training effects either. In addition to the aforementioned causes, one possible reason for that may be practice effects that are a consequence of repeated testing (Bartels *et al.*, 2010; Benedict & Zgaljardic, 1998). This means that when the same participants are tested with the same items two or more times, their performance gets better even though they do not actually train their skills. Thus, in an experimental study like ours, with quite a short intervention period, it is possible that all the participating groups improve their performance in post-tests because they have already practiced the same items at the pre-test phase. It is possible that these practice effects outperform training effects in a training study. In previous studies, it was also suspected that part of the positive WM intervention results might result from pre- and post-test tasks that excessively resemble the training tasks (Shipstead *et al.*, 2012). In our study, the tasks used in combined WM and counting training had WM demands related to short-term storage and processing of information, but the tasks did not closely resemble the pre- and post-tests. It is possible that because of that, the children in the WM and Counting Group did not seem to benefit from WM-based training.

In conclusion, our results support the previously presented evidence (Ramani & Siegler, 2008; Siegler & Ramani, 2008; Whyte & Bull, 2008) that training counting skills by playing

numerical games in preschool and kindergarten context seems to be a promising method to improve children's early math skills. It also offers possibilities to get acquainted with numbers and number related activities for those children who do not have possibilities for that at home (see e.g., Siegler & Ramani, 2008; Tudge & Doucet, 2004). Our results also show that domain-specific counting training is more effective in improving early numerical performance than the domain-general combined WM/counting training. Based on our results, preschool-aged children, who represent various performance levels in counting, do not seem to benefit from short period group training in WM skills with domain specific scope (counting). However, it should be noted that targeting domain-general combined WM/counting training to a group of low-performing children might produce more positive results, as observed by Kroesbergen *et al.* (2012). Moreover, based on our results one cannot conclude that WM training as such is ineffectual. It is possible that more intensive, pure WM training would enhance both WM skills and counting skills. Future studies should be conducted to further investigate the issue.

We gratefully acknowledge the contribution of the children, parents and kindergarten teachers. This research was supported by Grants from the Finnish Cultural Foundation and the Emil Aaltonen Foundation.

REFERENCES

- Alloway, T. P., Gathercole, S. E., Adams, A.-M., Willis, C., Eaglen, R. & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, 23, 417–426.
- Alloway, T. P., Gathercole, S. E., Willis, C. & Adams, A.-M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology*, 87, 85–106.
- Aunio, P., Hautamäki, J. & Van Luit, J. H. E. (2005). Mathematical thinking intervention programmes for preschool children with normal and low number sense. *European Journal of Special Needs Education*, 20, 131–146.
- Aunio, P. & Niemivirta, M. (2010). Predicting children's mathematical performance in grade one by early numeracy. *Learning and Individual Differences*, 20, 427–435.
- Aunola, K., Leskinen, E., Lerkkanen, M. K. & Nurmi, J. E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology*, 96, 699–713.
- Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.
- Baddeley, A. (1997). *Human memory: Theory and practice*. Hove: Psychology Press.
- Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.
- Baddeley, A. D. & Hitch, G. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.
- Bartels, C., Wegrzyn, M., Wiedl, A., Ackermann, V. & Ehrenreich, H. (2010). Practice effects in healthy adults: A longitudinal study on frequent repetitive cognitive testing. *BMC Neuroscience*, 11, 118–129.
- Benedict, R. B. & Zgaljardic, D. J. (1998). Practice effects during repeated administrations of memory tests with and without alternate forms. *Journal of Clinical & Experimental Neuropsychology*, 20, 339–352.
- Bull, R., Espy, K. A. & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, 33, 205–228.
- Bull, R. & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, 19, 273–293.
- Claessens, A., Duncan, G. J. & Engel, M. (2009). Kindergarten skills and fifth grade achievement: Evidence from the ECLS-K. *Economics of Education Review*, 28, 415–427.
- De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B. & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology*, 103, 186–201.
- Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P. *et al.* (2007). School readiness and later achievement. *Developmental Psychology*, 43, 1428–1446.
- Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hambry, A. & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology*, 26, 465–486.
- Friso-Van den Bos, I., Kolkman, M. E., Kroesbergen, E. H. & Leseman, P. P. M. (2014). Explaining variability: Numerical representations in 4- to 8-year old children. *Journal of Cognition and Development*, 15, 325–344.
- Friso-Van den Bos, I., Van der Ven, S. H. G., Kroesbergen, E. H. & Van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, 10, 29–44.
- Garon, N., Bryson, S. E. & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, 134, 31–60.
- Gathercole, S. E., Brown, L. & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of national curriculum attainment levels. *Educational and Child Psychology*, 20, 109–122.
- Gathercole, S. E., Tiffany, C., Briscoe, J. & Thorn, A. & ALSPAC team (2005). Developmental consequences of poor phonological short-term memory function in childhood: A longitudinal study. *Journal of Child Psychology and Psychiatry*, 46, 598–611.
- Geary, D. C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development*, 78, 1343–1359.
- Geary, D. C., Hoard, M. K. & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. *Journal of Experimental Child Psychology*, 74, 213–239.
- Geary, D. C., Hoard, M. K., Nugent, L. & Bailey, D. H. (2013). Adolescents' functional numeracy is predicted by their school entry number system knowledge. *PloS one*, 8, e54651. doi:10.1371/journal.pone.0054651
- Gallistel, C. R. & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition*, 44(1), 43–74.
- Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S. & Engle, R. W. (2014). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science*, 24, 2409–2419.
- Henry, L. A. & MacLean, M. (2003). Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities. *Educational and Child Psychology*, 20, 51–64.
- Hitch, G. J. (1978). The role of short-term working memory in mental arithmetic. *Cognitive Psychology*, 10, 302–323.
- Holmes, J. & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, 26, 339–366.
- Holmes, J., Gathercole, S. E. & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, 12, F9–F15.
- Jaeggi, S. M., Buschkuhl, M., Jonides, J. & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *PNAS*, 105, 6829–6833.
- Jarvis, H. & Gathercole, S. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology*, 20, 123–140.

- Jordan, N. C., Kaplan, D., Locuniak, M. N. & Ramineni, C. (2007). Predicting first-grade math achievement from developmental number sense trajectories. *Learning Disabilities Research & Practice*, 22, 36–46.
- Jordan, N. C., Kaplan, D., Oláh, L. & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development*, 77, 153–175.
- Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, 14, 317–324.
- Krajewski, K. & Schneider, W. (2009). Exploring the impact of phonological awareness, visual-spatial working memory, and preschool quantity-number competencies on mathematics achievement in elementary school: Findings from a 3-year longitudinal study. *Journal of Experimental Child Psychology*, 103, 516–531.
- Kroesbergen, E. H., Van de Rijt, B. & Van Luit, J. E. H. (2007). Working memory and early mathematics: Possibilities for early identification of mathematics learning disabilities. *Advances in Learning and Behavioral Disabilities*, 20, 1–19.
- Kroesbergen, E. H. & Van Luit, J. E. (2003). Mathematics interventions for children with special educational needs: A meta-analysis. *Remedial and Special Education*, 24, 97–114.
- Kroesbergen, E. H., Van Luit, J. E. H., Naglieri, J. A., Franchi, E. & Taddei, S. (2010). A cross-cultural study of PASS-processes and preparatory mathematics. *Journal of Psychoeducational Assessment*, 28, 585–593.
- Kroesbergen, E. H., Van't Noordende, J. E. & Kolkman, M. E. (2012). Number sense in low performing kindergarten children: Effects of a working memory and a number sense training. In Z. Breznitz, O. Rubinsten, V.J. Molfese & D. Molfese, (Eds.) *Reading, writing, mathematics and the developing brain: Listening to many voices, Literacy Studies 6* (pp 295–313). New York: Springer Publications.
- Kroesbergen, E. H., Van't Noordende, J. E. & Kolkman, M. E. (2014). Training working memory in kindergarten children: Effects on working memory and early numeracy. *Child Neuropsychology*, 20, 23–37.
- Kyttälä, M. (2008). Visuospatial working memory in adolescents with poor performance in mathematics: Variation depending on reading skills. *Educational Psychology*, 28, 273–289.
- Kyttälä, M., Aunio, P. & Hautamäki, J. (2010). Working memory resources in young children with mathematical difficulties. *Scandinavian Journal of Psychology*, 51, 1–15.
- Kyttälä, M., Aunio, P., Lehto, J. E., Van Luit, J. E. H. & Hautamäki, J. (2003). Visuospatial working memory and early numeracy. *Educational and Child Psychology*, 20, 65–76.
- Kyttälä, M. & Lehto, J. (2008). Some factors underlying mathematical performance: The role of visuospatial working memory and non-verbal intelligence. *European Journal of Psychology of Education*, 22, 77–94.
- Locuniak, M. N. & Jordan, N. C. (2008). Kindergarten number sense to predict calculation fluency in second grade. *Journal of Learning Disabilities*, 41, 451–459.
- Logie, R. H. & Pearson, D. G. (1997). The inner eye and the inner scribe of visuo-spatial working memory: Evidence from developmental fractionation. *European Journal of Cognitive Psychology*, 9, 241–257.
- Melby-Lervåg, M. & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, 49, 270–291.
- Noël, M.-P. (2009). Counting on working memory when learning to count and to add: A preschool study. *Developmental Psychology*, 45, 1630–1643.
- Olesen, P. J., Westerberg, H. & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*, 7, 75–79.
- Passolunghi, M. C. & Costa, H. M. (2014). Working memory and early numeracy training in preschool children. *Child Neuropsychology*. doi: 10.1080/09297049.2014.971726.
- Passolunghi, M. C. & Lanfranchi, S. (2012). Domain-specific and domain-general precursors of mathematical achievement: A longitudinal study from kindergarten to first grade. *British Journal of Educational Psychology*, 82, 42–63.
- Passolunghi, M. C., Vercelloni, B. & Schadee, H. (2007). The precursors of mathematics learning: Working memory, phonological ability and numerical competence. *Cognitive Development*, 22, 165–184.
- Preßler, A.-L., Krajewski, K. & Hasselhorn, M. (2013). Working memory capacity in preschool children contributes to the acquisition of school relevant precursor skills. *Learning and Individual Differences*, 23, 138–144.
- Ramani, G. B. & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, 79, 375–394.
- Rasmussen, C. & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology*, 91, 137–157.
- Reuhkala, M. (2001). Mathematical skills in ninth-graders: Relationship with visuo-spatial abilities and working memory. *Educational Psychology*, 21, 387–399.
- Rutherford, A. *Introducing ANOVA and ANCOVA: A GLM approach*. London: Sage.
- Shipstead, Z., Redick, T. S. & Engle, R. W. 1. (2012). Is working memory training effective? *Psychological Bulletin*, 138, 628–654.
- Siegel, L. S. (1994). Working memory and reading: A life-span perspective. *International Journal of Behavioral Development*, 17, 109–124.
- Siegler, R. S. & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, 11, 655–661.
- Silverstein, A. B. (1982). Two-and four-subtest short forms of the Wechsler Adult Intelligence Scale-Revised. *Journal of Consulting and Clinical Psychology*, 50, 415–418.
- Toll, S.W.M., Van der Ven, S. H. G., Kroesbergen, E. H. & Van Luit, J. E. H. (2011). Executive functions as predictors of math learning. *Journal of Learning Disabilities*, 44, 521–532.
- Toll, S. W. M. & Van Luit, J. E. H. (2012). Early numeracy intervention for low-performing kindergartners. *Journal of Early Intervention*, 34, 243–264.
- Toll, S. W. M. & Van Luit, J. E. H. (2013). The development of early numeracy ability in kindergartners with limited working memory skills. *Learning and Individual Differences*, 25, 45–54.
- Tudge, J. R. H. & Doucet, F. (2004). Early mathematical experiences: observing young Black and White children's everyday activities. *Early Childhood Research Quarterly*, 19, 21–39.
- Van de Rijt, B. A. M. & Van Luit, J. E. H. (1998). Effectiveness of the Additional Early Mathematics program for teaching children early mathematics. *Instructional Science*, 26, 337–358.
- Van De Rijt, B. M. & Van Luit, J. H. (1999). Milestones in the development of infant numeracy. *Scandinavian Journal of Psychology*, 40, 65–71.
- Van de Rijt, B. A. M., Van Luit, J. E. H. & Pennings, A. H. (1999). The construction of the Utrecht Early Mathematical Competence Scale. *Educational and Psychological Measurement*, 59, 289–309.
- Van Luit, J. E. H., Van de Rijt, B. A. M. & Aunio, P. (2006) *Early Numeracy Test, Finnish edition* [Lukukäsitetesti]. Helsinki, Finland: Psykologien kustannus.
- Von Aster, M. G. & Shalev, R. S. (2007). Number development and developmental dyscalculia. *Developmental Medicine & Child Neurology*, 49, 1469–8749.
- Wechsler, D. (2010). *Wechsler Intelligence Scale for Children III*. Helsinki: Psykologien Kustannus Oy.
- Westerberg, H. & Klingberg, T. (2007). Changes in cortical activity after training of working memory – a single-subject analysis. *Physiology & Behavior*, 92, 186–192.
- Wilson, J. T. L., Scott, J. H. & Power, K. G. (1987). Developmental differences in the span of visual memory for pattern. *British Journal of Developmental Psychology*, 5, 249–255.
- Wilson, K. M. & Swanson, L. (2001). Are mathematics disabilities due to a domain-general or a domain-specific working memory deficit? *Journal of Learning Disabilities*, 34, 237–248.
- Whyte, J. C. & Bull, R. (2008). Number games, magnitude representation, and basic number skills in preschoolers. *Developmental Psychology*, 44, 588–596.

Received 29 April 2014, accepted 11 March 2015