Working memory and early numeracy training in preschool children

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Many factors influence children's performance in mathematical achievement, including both domain-specific and domain-general factors. This study aimed to verify and compare the effects of two types of training on early numerical skills. One type of training focused on the enhancement of working memory, a domain-general precursor, while the other focused on the enhancement of early numeracy, a domain-specific precursor. The participants were 48 five-year-old preschool children. Both the working memory and early numeracy training programs were implemented for 5 weeks. The results showed that the early numeracy intervention specifically improved early numeracy abilities in preschool children, whereas working memory intervention improved not only working memory abilities but also early numeracy abilities. These findings stress the importance of performing activities designed to train working memory abilities, in addition to activities aimed to enhance more specific skills, in the early prevention of learning difficulties during preschool years.

***Keywords*:** Working memory; Working memory training; Mathematical precursors; Cognitive abilities; Preschool.

Several recent studies investigated precursors of mathematical learning in preschool children. Competencies that specifically predict mathematical abilities may be considered domain-specific precursors, such as early numeracy, whereas general cognitive abilities, such as working memory, that may predict performance not only in mathematics but also in other school subjects may be considered domain-general precursors (Gathercole, Brown, & Pickering, 2003; Gathercole, Pickering, Knight, & Stegmann, 2004; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Passolunghi & Lanfranchi, 2012; Träff, 2013). The key role of both domain-specific and domain-general precursors in the development of mathematical abilities has led researchers to design studies to investigate the possibility of developing training programs to improve these abilities in children. These training programs may be crucial in the prevention of mathematical learning difficulties during preschool years.

The number of students with mathematical difficulties has greatly increased over the last 20 years (Swanson, 2000). It seems that the estimated prevalence of children that

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Address correspondence to Maria Chiara Passolunghi, Department of Life Sciences, Psychology Unit "Gaetano Kanizsa," University of Trieste, via Weiss, 21 (Building W), 34128 Trieste, Italy. E-mail: passolu@units.it experience a substantive learning deficit in at least one area of mathematics is between 5% and 10% (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Shalev, 2007; Shalev, Manor, & Gross-Tsur, 2005). These students that find mathematics difficult choose not study math in secondary or further education (Brown, Askew, Millett, & Rhodes, 2003). This choice must be considered a risk factor as several studies found that mathematical abilities predict financial and educational success, particularly for women (Geary, Hoard, Nugent, Bailey, & Krueger, 2013; Parsons & Bynner, 2005). Given these findings, it should be considered important to intervene as soon as possible in order to improve basic academic skills and to reduce future learning difficulties.

Although some efforts have been made to improve precursors of mathematical learning, it is still unclear what the influence and the different effects of training focused on the enhancement of either domain-general or domain-specific precursors would be. In this study, our aim was to verify and to compare the effects on early numerical competence of two types of training in a sample of 5-year-old preschool children. One type of training focused on the enhancement of domain-general precursors, working memory abilities, and the other focused on the enhancement of domain-specific precursors, early numeracy abilities.

Domain-General Precursors: The Role of Working Memory

Working memory (WM) refers to a mental workspace, which enables a person to hold information in mind while simultaneously performing other complex cognitive tasks (e.g., mathematical processing) (Holmes & Adams, 2006).

Various models of the structure and function of working memory exist, but the present study considered the multicomponent model of working memory initially proposed by Baddeley and Hitch (1974; see also Baddeley, 1986, 2000). This model consists of three main parts. The two passive modality-specific systems (i.e., the phonological loop and visual-spatial sketchpad) are specialized for processing language-based and visuospatial information, respectively. The central executive, which is not modality specific, coordinates the two slave systems and is responsible for a range of functions, such as the attentional control of actions (e.g., inhibiting irrelevant information, shifting attention, updating information). The distinction between the central executive system and specific memory storage systems (i.e., the phonological loop and visuospatial sketchpad) in some ways parallel the distinction between working memory (WM) and short-term memory (STM). The WM is considered an active system that involves both storage and processing of information, while STM typically involves situations in which the individual passively holds small amounts of information, as required in span forward tasks (Cornoldi & Vecchi, 2003; Swanson & Beebe-Frankenberger, 2004).

Several studies demonstrated that WM is a key domain-general predictor of mathematical competence. WM abilities seem to be related both to early numeracy skills and to later mathematical skills (Alloway & Alloway, 2010; Alloway & Passolunghi, 2011; De Smedt et al., 2009; Friso-Van den Bos, Van der Ven, Kroesbergen, & Van Luit, 2013; Gathercole & Pickering, 2000; Gersten, Jordan, & Flojo, 2005; Jordan, Kaplan, Nabors Olah, & Locuniak, 2006; Passolunghi & Lanfranchi, 2012; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014). Indeed, even the simplest mathematics calculations require WM processes: temporary storage of problem information, retrieval of relevant procedures, and processing operations to convert the information into numerical output (Brainerd, 1983). These same processes are needed even for simple number comparison tasks: The child needs to map the different number symbols onto the corresponding quantities, to store them into memory, and then to integrate this with the incoming information to perform the task (Kroesbergen, Van ‘t Noordende, & Kolkman, 2014).

Further evidence in favor of the importance of working memory in children’s mathematical skills has been provided by longitudinal studies that demonstrated that working memory performance in preschoolers predicts mathematical achievement several years after preschool (Bull, Espy, & Wiebe, 2008; Gathercole et al., 2003; Mazzocco & Thompson, 2005; Passolunghi & Lanfranchi, 2012). Specifically, several studies showed a direct influence of working memory on mathematical achievement in first and second graders (De Smedt et al., 2009; Passolunghi, Mammarella, & Altoè, 2008; Passolunghi, Vercelloni, & Schadee, 2007). Moreover, several studies in the field of mathematical learning disabilities demonstrated that poor WM ability in children is related to poor math performance (Alloway, 2009; Gathercole & Pickering, 2000; Kroesbergen, Van Luit, & Naglieri, 2003; Passolunghi & Siegel, 2004; Raghubar, Barnes, & Hecht, 2010; Van der Sluis, van der Leij, & de Jong, 2005).

Domain-Specific Precursors: Early Numeracy Abilities

Another important aspect of the acquisition of mathematical competence is represented by domain-specific components: foundational-specific skills that necessarily underlie the development of arithmetic skills. Such core skills that predict children’s performance in mathematics have been referred to under the general term “early numeracy abilities” and include skills such as counting ability, one-to-one correspondence, making quantity comparison, and forming representation of numerical magnitudes in the form of a mental number line (Gersten et al., 2005; Griffin, 2004; Jordan et al., 2006; Van de Rijt & Van Luit, 1999). Among these abilities, counting ability, in particular verbal counting, seems to be one of the most discriminating and efficient precursors of early mathematics learning (Mazzocco & Thompson, 2005; Passolunghi et al., 2007). Counting ability implies being able to understand the one-to-one relation between objects in a set and their numerical representations and some studies show individual differences in the level of counting ability in subjects with different scores in arithmetic tasks (see Geary, Hoard, & Hamson, 1999). In addition, research demonstrated that accurate mental number-line representations and quantity discrimination are strong predictors of arithmetic and mathematics skills when children enter school (Booth & Siegler, 2006; Gersten et al., 2005; Jordan et al., 2006; Siegler & Booth, 2004).

Therefore, early numeracy abilities are considered strong predictors of mathematics skills when children enter school (Booth & Siegler, 2006; Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013; Siegler & Booth, 2004). In particular, these abilities assessed in preschool years have been shown to predict mathematical performance in the first grade (Aunio & Niemivirta, 2010; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Passolunghi & Lanfranchi, 2012) and second grade (Locuniak & Jordan, 2008). On the other hand, weak early numeracy abilities and less accuracy in spatially map numbers have been shown to contribute to lower calculation skills and mathematical learning disabilities (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Gersten et al., 2005; Landerl, Fussenegger, Moll, & Willburger, 2009; Mazzocco & Thompson, 2005; Rousselle & Noël, 2007).

Early Numeracy Training

Improving early numeracy abilities in preschool children has been demonstrated using both formal and informal instruction, even before the children's entrances into primary school (Ramani & Siegler, 2008; Ramani, Siegler, & Hitti, 2012; Siegler & Ramani, 2008; Whyte & Bull, 2008). Low numeracy can be caused by a lack of experience with numbers and number-related activities, and different types of interventions could be used to build early numeracy abilities. It has been shown that using numerical board games and activities at the preschool level improves children's numerical estimation skills and number comprehension (Ramani & Siegler, 2008; Siegler & Ramani, 2008; Whyte & Bull, 2008). Indeed, these numerical games provide multiple cues to both the order of numbers and numerical magnitudes (Siegler & Booth, 2004). Number-line estimation, counting, numerical magnitude comparison, and numerical identification all improved through the use of linear numerical board games (Ramani & Siegler, 2008), whereas only number comprehension and counting skills improved using nonlinear numerical games (Whyte & Bull, 2008). Moreover, various programs seek to specifically target emergent mathematics skills through activities that are designed to promote skills that the literature suggests are important, including counting, recognizing and writing numbers, one-to-one correspondence, comparisons, change operations, and understanding numbers and quantities (Arnold, Fisher, Doctoroff, & Dobbs, 2002; Greenes, Ginsburg, & Balfanz, 2004; Starkey, Klein, & Wakeley, 2004; Young-Loveridge, 2004). In conclusion, intervening in the preschool years to enhance early numeracy skills is possible and could be an important strategy to prevent subsequent underachievement in mathematics learning.

Working Memory Training

Other studies investigated whether mathematical learning problems can be overcome by training designed to enhance working memory abilities. The debate regarding the effects of WM training is still open: Some studies show positive effects of WM training on arithmetic abilities in primary-school children using computerized or school-based training procedures (Alloway, Bibile, & Lau, 2013; Holmes & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009; Kuhn & Holling, 2014; St. Clair-Thompson, Stevens, Hunt, & Bolder, 2010; Witt, 2011). Other authors questioned the effectiveness of WM training concluding that there is no convincing evidence of the generalization of working memory training to other skills (Melby-Lervåg & Hulme, 2013). However, the possibility that cognitive training applied to younger individuals tends to lead to a significantly more widespread transfer of training effects should be considered (Wass, Scerif, & Johnson, 2012).

Holmes et al. (2009) provided the first evidence of the efficacy of the computerized "Cogmed" training in overcoming common impairments in working memory and associated learning difficulties in 10-year-old children. They proposed different training tasks that involve the temporary storage and manipulation of either sequential visuospatial information, verbal information, or both for a period of 5 to 7 weeks. The majority of the children who completed the program improved their working memory substantially, and a significant increase in mathematics performance was also found 6 months after training. St. Clair-Thompson et al. (2010) also showed that a computerized working memory training strategy resulted in significant improvements in tasks that assess the phonological loop, the central executive, mental arithmetic, and following instructions in the classroom. Enhancing mathematical abilities in 9- to 10-year-old children is also possible using individual school-based working memory training (Witt, 2011). This study suggested that children who underwent working memory training made significantly greater gains in the trained working memory tasks, as well as on an untrained visuospatial working task, than a matched control group. Moreover, the training group also made significant improvements in mathematics performance.

Only a few studies have explored the possibility of enhancing working memory abilities in kindergartners using specific working memory training (Dowsett & Livesey, 2000; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). A study by Kroesbergen et al. (2014) systematically investigated the transfer effect of WM training on early numeracy. This study demonstrated that low-performing children who participated in working memory intervention significantly improved their working memory skills. Furthermore, their early numeracy skills also improved.

The Present Study

The findings described above show promising effects of both working memory training and early numeracy training on children’s mathematical performance, but also a lack of any comparisons of the effects of the two types of training on early numerical abilities in mainstream preschool settings. In the present study, our aim was to investigate the effects on early numeracy of two specific training programs that focus on either working memory or early numeracy in a sample of mainstream preschool children. For this purpose, we compared performance of a domain-specific early numeracy training group, a domain-general WM training group and an untrained control group.

Previous longitudinal correlational studies showed that working memory is a precursor of early numeracy abilities and mathematics achievement (Alloway & Alloway, 2010; De Smedt et al., 2009; Passolunghi & Lanfranchi, 2012; Passolunghi et al., 2007). Accordingly, we expected that our training focused on the improvement of working memory abilities should improve not only working memory but will also produce a transfer effect on early numeracy. This hypothesis is in line with previous studies dealing with WM training and transfer effects on math abilities in primary school children and kindergarten (Holmes et al., 2009; Kroesbergen et al., 2014; St. Clair-Thompson et al., 2010; Witt, 2011).

Regarding early numeracy abilities, it has been proved that this domain-specific precursor predicts later mathematical achievement (De Smedt et al., 2009; Gersten et al., 2005; Jordan et al., 2006; Passolunghi & Lanfranchi, 2012; Passolunghi et al., 2007). Moreover, several studies proved that preschool training and intervention on early numeracy lead to enhancement of emergent mathematic skills (Arnold et al., 2002; Greenes et al., 2004; Ramani & Siegler, 2008; Siegler & Ramani, 2008; Starkey et al., 2004; Whyte & Bull, 2008; Young-Loveridge, 2004). However, there is no evidence proving that early numeracy abilities can predict the performance in a more general domain as working memory, and one study demonstrated no transfer effects of early math training on working memory abilities of low-performing children (Kroesbergen, Van ‘t Noordende, & Kolkman, 2012). Therefore, we expect that our early numeracy training will have a more specific and limited effect on early numeracy abilities compared to the WM training.

METHOD

Participants

The participants were 5-year-old preschool children attending their final year of preschool. After consent was provided by the schools, letters were given to parents/guardians of each child for individual consent. Children with significant developmental delays (as identified by local educational services) were excluded. Of the children from whom consent was received, 48 were randomly selected. The socioeconomic status of the sample was primarily middle class, established on the basis of school records. The children were recruited through six preschools located in an urban area of northern Italy and were randomly allocated to one of three groups: 15 children (M_{age} = 65.8 months, *SD* = 2.1, seven girls) underwent working memory training; 15 children (M_{age} = 64.67 months, *SD* = 2.9 six girls), underwent early numeracy training; and a control group of 18 children (M_{age} = 64.4 months, *SD* = 3.2, nine girls) performed their usual school activities in the classroom.

Procedure

The experimenters were three female Italian master students trained by the authors. Two experimenters carried out pre- and postassessments, while the third experimenter carried out both of the training programs. The experimenters who conducted the assessments were blind to the group the children belonged to. The authors monitored the training implementation once a week and the interrater agreement on the reliability of treatment implementation was 92%.

The working memory training included different paper-and-pencil tasks that were designed to enhance all three components of Baddeley's working memory model (Baddeley, 1986). The early numeracy training included different paper-and-pencil tasks that were designed to enhance early numerical abilities such as counting, number-line representation, one-to-one correspondence between quantities and numerals, and quantity comparison. Over 5 successive weeks, the children under experimental conditions participated in 10 training sessions (twice weekly) implemented in small groups of five children. Training duration was 1 hour per session.

Before and after training, children's working memory ability and early numeracy ability were assessed. Both at the pretest and at the posttest stage, the children were individually tested in two sessions. In the first session, the memory (WM and STM) skills of the children were measured, and, in the second session, early numeracy skills were measured. The assessments took place in a quiet room inside the schools and each session lasted about 20 minutes.

Pre- and Posttraining Assessments

Visuospatial Short-Term Memory. During pathway recall (Lanfranchi, Cornoldi, & Vianello, 2004), the child was shown a path taken by a small frog on a 3 × 3 or 4 × 4 chessboard. Then, the child had to recall the pathway immediately after presentation by moving the frog from square to square, reproducing the experimenter's moves. The task had four levels of difficulty, depending on the number of steps in the frog's path and dimensions of the chessboard (3 × 3 in the first level with two steps and 4 × 4 in the other levels, with two, three, and four steps, respectively). A self-terminating procedure was employed: Participants performed the tasks until they were able to solve at least one item out of two at a specific level. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8. The test-retest reliability for forward recall of paths is .70.

Visuospatial Working Memory. The visuospatial working memory task required a visuospatial dual task (Lanfranchi et al., 2004). The child had to remember the frog's starting position on a path on a 4 × 4 chessboard, in which one of the 16 cells was colored red. The child also had to tap on the table when the frog jumped onto the red square. The task had four different levels of difficulty, depending on the number of steps in the path (i.e., two, three, four, and five steps, respectively). A self-terminating procedure was employed: Participants performed the tasks until they were able to solve at least one item out of two at a specific level. The score of 1 was given for every trial performed correctly, with the child both remembering the first position of the pathway and performing the tapping task. Otherwise, a score of 0 was given. In each task, the minimum score was 0 and the maximum score was 8. The test-retest reliability for the visuospatial dual task is .81.

Verbal Short-Term Memory. The word-recall forward task (Passolunghi & Siegel, 2001) was used to tap children's verbal STM capacity. In this task the child was presented with lists of two to six words and was required to repeat the list immediately and in the same order as presented. A self-terminating procedure was employed: Participants performed the tasks until they were able to solve at least one item out of two at a specific level. The span was considered to be correct if the child recalled all of the items in the correct order. The test-retest reliability for forward recall of words is .88.

Verbal Working Memory. During the verbal dual task (Lanfranchi et al., 2004), the child was presented with a list of two to five 2-syllable words and was asked to remember the first word on the list and to tap on the table when the word "palla" (ball) was presented. A self-terminating procedure was employed: Participants performed the tasks until they were able to solve at least one item out of two at a specific level. A score of 1 was given when the initial word of the series was remembered correctly at the same time the dual task was performed. The test-retest reliability for verbal dual task is .84.

Early Numeracy Abilities. We assessed numerical competence using the Early Numeracy Test (ENT; Van Luit, Van de Rijt, & Pennings, 1994). The ENT consists of 40 items and has two analogous versions, Version A and Version B. In this study, only Version A was used. The test evaluates different aspects of young children's numerical competence, such as concepts of comparison, classification, correspondence, seriation, use of number words, structured counting, resultative counting, and general knowledge of numbers. The items are scored, with 0 for a wrong answer and 1 for a right answer. The maximum number of points is 40. The ENT was developed as a one-dimensional test (van de Rijt, van Luit, & Pennings, 1999). The test-retest reliability for ENT is .84.

Training Programs

Working Memory Training. The WM training was conducted in groups of five children for 1 hour, two times per week. The full training program consisted of eight different games grouped into four different categories: verbal WM games, verbal STM games, visuospatial WM games, and visuospatial STM games. In each session, two games were played. The games for each session were selected in such a way that within one week all children were exposed to one game from each of the categories. The order of presentation of the games was the same in each group. The children participated in the activity one after the other. The training was adaptive with the instructor adapting the tasks to the child's performance (e.g., if the child failed to remember three items, on the next occasion the instructor asked for two items and, after a successful repetition of two items, asked for three again).

Verbal WM Games. The first category of games tapped verbal WM abilities. The game "Animals' Home" required the temporary storage and manipulation of sequences of spoken verbal items. Children were presented with lists of words. When they heard the name of an animal, they together had to make its noise and had to keep in mind the first word of the list. For each presentation, a child was asked to recall the first word of the list. The game "Mysterious Objects Back" was designed to enhance backward span ability. Children were presented with lists of words orally and had to recall the list in the reverse order.

Visuospatial WM Games. The second category of games tapped visuospatial WM abilities. The game "Jellyfishes" required a visuospatial dual task. A matrix was positioned on the floor. Children were presented with a path and had to recall the first step of the path with the noise given by an interference task. In the "Game of Cards Back," some cards with pictures were presented, one at a time, and the children had to recall the list in the reverse order.

Verbal STM Games. The third category tapped verbal STM abilities. These games ("Mysterious Objects" and "Line of Words") were designed to enhance forward span ability. Children were presented with lists of words and had to recall the lists in the correct order.

Visuospatial STM Games. The fourth category tapped visuospatial STM abilities. These games required the immediate serial recall of visuospatial information. For the game "Farmers," a matrix positioned on the floor was used and children had to remember paths of different lengths. In the "Game of Cards," some cards with pictures were presented, one at a time, and the children had to recall the list in the correct order.

Early Numeracy Training. The early numeracy training was conducted in groups of five children for 1 hour, two times a week. The full training program consisted of eight different games grouped into four different categories: counting, linear representation of numbers, relationships between numbers and quantities, and comparison of quantities. In each session, two games were played. The games for each session were selected in such a way that within one week all children were exposed to one game from each of the categories. The order of presentation of the games was the same in each group. The children participated in the activity one after the other. The training was adaptive with the instructor adapting the tasks to the child's performance (e.g., if the child failed to perform the task, on the next occasion the instructor presented an easier one. After a successful performance, the instructor increased the difficulty level of the task again). During the first and the second week, children played games that focused on the numbers 1 to 10. During the third week, numbers 11 to 20 were introduced.

Counting Games. The first category of games tapped counting abilities. The game "Fingers" required the verbalization of counting sequences through finger counting. The other game ("Numbers Rhyme") consists in the teaching of a rhyme that made use of the number. The numbers rhyme was presented with a series of cards that illustrated the numbers.

Linear Number Board Games. The second category of games tapped the linear representation of numbers. The first was a linear-number board game ("Number Path") in which the children had to complete a path. Each child alternatively threw dice. According to the number shown on the dice, the child should move on a number line. On every square of the path were instructions to perform a numerical task. In the second game ("Number-Line Game"), the children had to extract from a box some cards that showed numbers and had to place them in the correct position on a line, with or without the references given by the vertical bars, to build the line of numbers.

Number—Quantity Linkage Games. The third category of games tapped the identification of relationships between numbers and quantities. In the first game ("Tombola"), the children had to connect the quantities represented on their cards with the corresponding numbers extracted. Another game ("Pairs") challenged the children to remember the locations of cards placed on a grid with the goal of pairing cards that represented numbers with cards that represented the corresponding quantity.

Quantity Comparison Games. The fourth category tapped the comparison of quantities ("more than" and "less than"). In the game "Cats and Mice," children engaged in an activity in which pictures of two cats were shown. Each cat was given a quantity of mice. The goal of the game was to identify how many mice were given to each cat and to decide which of the two cats had more mice. The game "Tokens" required children to compare quantities of coins scattered on the table.

RESULTS

Mean and standard deviation of pretest and posttest scores of the three groups are presented in Table 1. A series of analyses of variance (ANOVAs) established no significant differences at pretest between the three groups in any measure: early numeracy, $F(2, 45) = 1.21$, $p = .31$, $\eta_p^2 = .05$, visuospatial STM, $F(2, 45) = 0.05$, $p = .95$, $\eta_p^2 = .002$, visuospatial working memory, $F(2, 45) = 1.30$, $p = .28$, $\eta_p^2 = .05$, verbal STM, $F(2, 45) = 1.18$ $p = .32$, $\eta_p^2 = .05$, verbal working memory, $F(2, 45) = 0.23$, $p = .79$, $\eta_p^2 = .01$.

Table 1 Pre- and Posttest Scores and Univariate Test Results for Gain Differences Between the Conditions.

	Working memory training group				Early numeracy training group				Control group				
	Pretraining		Posttraining		Pretraining		Posttraining		Pretraining		Posttraining		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	*F*
Verbal STM	4.73	0.80	4.93	0.88	5.00	1.36	5.40	1.30	5.28	0.82	5.28	0.75	0.69
Verbal WM	3.60	1.63	5.73	1.67	3.40	1.96	3.87	2.03	3.17	1.85	3.56	1.65	7.62*
Visuospatial STM	5.47	1.55	6.27	1.39	5.33	0.72	5.60	1.24	5.39	1.14	5.56	1.25	1.42
Visuospatial WM	4.93	2.05	6.73	1.16	3.93	2.63	4.60	2.67	3.72	2.05	3.44	2.12	10.46*
Early Numeracy	23.53	6.75	28.00	6.91	20.07	8.07	28.33	5.39	19.89	7.21	21.56	6.13	17.96*

Note. $^*p < .01$.

There was no difference between the three groups for chronological age, $F(2, 45) = 1.06$ $p = .35$, $\eta_p^2 = .04$, and there was no significant difference for the amount of intervention sessions received between the two training groups; $F(1, 34) = 0.70$, $p = .41$, $\eta_p^2 = .02$. Therefore, these factors were not further included as covariates in the analyses.

To examine performance gains between the pretest and posttest sessions for all of the tasks, we conducted analyses of covariance (ANCOVA) with the Group (working memory training, early numeracy training, and control) used as the factor, Pretest Scores used as the covariate, and Difference Scores (posttest minus pretest) examined as the dependent variable. Bonferroni-adjusted post hoc pairwise comparisons of Difference Scores (posttest minus pretest) were also conducted.

For the comparisons of the gain difference between groups, η_p^2 was used as a measure of effect size. The criteria of Cohen (1988) were used to classify the effect sizes: small effect: $\eta_p^2 = .01$; medium effect: $\eta_p^2 = .06$; and large effect: $\eta_p^2 = .14$. Effect sizes (Cohen's *d*) for post hoc pairwise comparisons are also reported; small effect $d = .20$; medium effect $d = .50$; large effect $d = .80$.

The ANCOVA on early numeracy gain scores revealed a significant difference between groups after controlling for the effect of pretest scores, $F(2, 44) = 17.96$, $p < .001$, $\eta_p^2 = .45$, reflecting the differential effect of treatments. Bonferroni-adjusted post hoc pairwise comparisons indicated that the working memory group displayed larger improvement compared to the control group ($M_{diff} = 3.82$, $p = .005$, $d = .80$). Also the early numeracy group displayed larger improvement compared to the control group ($M_{diff} = 6.65$, $p < .001$, $d = 1.63$). The gain difference between the two intervention groups did not reach statistical significance ($M_{diff} = 2.83$, $p = .06$, $d = .95$).

The ANCOVA on the visuospatial working memory gain scores revealed a significant difference between groups, $F(2, 44) = 10.46$, $p < .001$, $\eta_p^2 = .32$, reflecting differential effects of training. Bonferroni-adjusted post hoc pairwise comparisons of performance gain differences indicated that children in the working memory group had a significantly greater gain compared with the control group ($M_{diff} = 2.52$, $p < .001$, $d = 1.16$), whereas no significant difference was found between the early numeracy group and the control group ($M_{diff} = 1.02$, $p = .19$, $d = .58$). The gains produced in the working memory group were significantly higher than those in the early numeracy group ($M_{diff} = 1.50$, $p = .03$ $d = .90$).

The ANCOVA of the verbal working memory gain scores revealed a significant difference between groups, $F(2, 44) = 7.62$, $p = .001$, $\eta_p^2 = .25$, reflecting the differential effects of training. Bonferroni-adjusted post hoc pairwise comparisons revealed that the improvement in performance from pre- to posttest was significantly greater in the working memory group than in the control group ($M_{diff} = 1.96$, $p = .002$, $d = .97$), whereas no significant difference was found between the early numeracy group and the control group ($M_{diff} = 0.19$, $p = 1$, $d = .04$). The gains produced in the working memory group were significantly higher than those in the early numeracy group ($M_{diff} = 1.76$, $p = .009$, $d = .96$).

The ANCOVA of the STM results revealed no interactions for verbal STM, $F(2, 44) = 0.69$ $p = .51$, $\eta_p^2 = .03$, or visuospatial STM, $F(2, 44) = 1.42$, $p = .25$, partial $\eta^2 = .06$.

DISCUSSION

The present study examined the effects of working memory training and early numeracy training on early numerical abilities in preschoolers, and the effects of these two types of training on the different components of working memory. As expected, our findings showed that only the children in the WM training group increased their working memory skills. More interestingly, not only the children in the early numeracy training group but also the children in the WM training group showed substantial gains in early numeracy abilities.

Regarding the early numeracy training, the group of children that received this type of training exhibited a significant enhancement of early numeracy abilities compared to the control group. This result confirms previous findings about the possibility of improving early numeracy skills in preschool children using numerical games and activities, even before their entrance into primary school (e.g., Ramani & Siegler, 2008; Whyte & Bull, 2008). However, children in the early numeracy training group did not significantly improve working memory abilities or STM abilities when compared with the control group and the working memory training group. The improvement was not significant with regard to the verbal component of STM and working memory, or for the visuospatial component of STM and working memory. These findings stressed the specificity of the effect of the early numeracy training on early numerical skills, given that no working memory or STM measures improved in this group.

More importantly, this study showed that the group that received working memory training exhibited a significant enhancement of both working memory abilities and early numeracy abilities. Significant increases in verbal and visuospatial working memory abilities were observed in the working memory training group compared with the control group and the early numeracy training group. This encouraging result is consistent with previous studies of working memory training in school-aged children and preschoolers (Dowsett & Livesey, 2000; Kroesbergen et al., 2014; Röthlisberger et al., 2012; Thorell et al., 2009). The WM training used effectively improved memory skills that are supported by the central executive component of Baddeley's model that is the most strongly predictive of a broad range of learning achievement including mathematics (De Smedt et al., 2009; Gathercole et al., 2003; Passolunghi et al., 2007).

Regarding the transfer effects of the WM training on school learning, children in the WM training group significantly enhanced their early numeracy abilities. The gain obtained in the working memory training group did not differ significantly from the gain obtained in the early numeracy training group. This result shows that the working memory training effect can be transferred to untrained and specific early numeracy abilities in mainstream preschool children. Moreover, this finding suggests the possibility of going beyond the correlational approach used in previous studies (De Smedt et al., 2009; Passolunghi & Lanfranchi, 2012; Passolunghi et al., 2007) and supports the idea of a possible causal relationship between domain-general working memory abilities and domain-specific numerical competence in preschoolers (Kroesbergen et al., 2014). Our results about the transfer effects of WM training are consistent with previous studies dealing with the effects of working memory training on mathematical achievement or early numeracy skills with older children and low-performing kindergarteners (Holmes et al., 2009; Kroesbergen et al., 2014; Kuhn & Holling, 2014; St. Clair-Thompson et al., 2010; Witt, 2011). However, a recent meta-analysis (Melby-Lervåg & Hulme, 2013) stated that there was no convincing evidence of the generalization of working memory training to other skills. However, the possibility that the role of working memory training could vary with development should be considered. Most of the studies investigating the effects of WM training focused on school-aged children, while only a few studies have explored the possibility of enhancing working memory (and related early numeracy abilities) in younger children, as were examined in the present study. It is entirely possible that the effects of WM training might be stronger in younger children when the neural system is more malleable to experience (Wass et al., 2012).

Working memory training, similar to early numeracy training, had no significant impact on verbal or visuospatial STM abilities. This finding may be attributable to the structure of the STM tasks that involved situations in which small amounts of material are passively held, without any manipulation of the to-be-recalled information, and then reproduced in the same order of presentation (e.g., forward digit or word-span tasks). The passive recall of information may be considered a measure that is stable and more difficult to improve by training procedures, whereas working memory skills can be improved through the acquisition of appropriate strategies to improve information-processing skills.

The findings of the present study have several practical implications for intervention. Some previous studies used computerized training procedures to examine the possibility to improve WM abilities and early numeracy abilities (Alloway et al., 2013; Holmes et al., 2009; Kuhn & Holling, 2014; St. Clair-Thompson et al., 2010). In this study, we decided to develop group-based intervention programs because we consider this modality easy to integrate into preschool activities and because it promotes motivation and peer-based learning (Ramani et al., 2012). The present results regarding the positive effects of the early numeracy training and the WM training used may contribute to plan interventions in preschool. Performing training activities such as those presented in the this study, as well as computerized training, may help children to improve cognitive precursors fundamental in future school learning encouraging the prevention of learning difficulties at the preschool level. In particular, different studies highlighted the great importance of WM in a range of cognitive skills including mathematics (see Cowan & Alloway, 2008). Thus, the development of different types of WM training programs may be crucial in planning interventions for the early prevention of learning difficulties in different school subjects.

The present study has some limitations. The first of these regards the lack of information about the durability of any gains made by training. It is important to examine whether beneficial effects of preschool training on early numerical competence and working memory are maintained when children entered primary school (Melby-Lervåg & Hulme, 2013). Moreover, it should also be noted that our positive effects should be interpreted with caution because the size of the sample was relatively small, which made the results sensitive to random effect. A final consideration for future research regards the investigation of the effects of WM training in preschoolers who are considered to be at risk for developing learning disabilities. In fact, WM training could be particularly appropriate for low-performing preschool children in order to minimize the future learning difficulties that result from WM deficits. Moreover, future studies may consider introducing more tasks to assess working memory abilities and numerical competence to better investigate the transfer effect of working memory training.

In summary, we found that early numeracy training proved to be effective in improving early numerical skills, and working memory training had a significant effect not only on memory but also on early numeracy abilities. These results stress the importance of performing activities designed to train working memory abilities, in addition to activities aimed to enhance more specific skills in preschool years. More research is needed to investigate the possibility that early numerical abilities can be enhanced using different training procedures and thus to investigate the causal mechanism of this pattern of results.

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