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Applied Perspectives

Can Working Memory Training Improve Preschoolers' Numerical Abilities?

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Abstract

A large number of studies have pointed out the role of working memory throughout numerical development. Working memory capacities seem to be improved after training and some studies have observed an impact of working memory training on academic performance. In our study, we examined whether training visuo-spatial working memory (with Cogmed) enhances working memory abilities and numerical development in the short and middle term in 5-6 year-old children. Fourty six children were randomly assigned to the experimental condition (adaptive working memory training) or the control condition (non-adaptive, demo version). The program was implemented daily for a period of five weeks in both groups. We observed an immediate impact of the adaptive version on visuo-spatial sketchpad and visuo-spatial central executive abilities and a small impact on Arabic number comparison. No training effect was observed in verbal working memory, in counting, collection comparison and addition. Furthermore, the observed effects were not sustained ten weeks later. These results are discussed in the context of specific and general cognitive factors that support numerical development and we argue against the idea of developing general cognitive factors to efficiently boost numerical development.

Keywords: preschoolers, working memory training, Cogmed, numerical development, arithmetic

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Academic achievement, such as literacy and mathematics, has its roots in very basic skills, e.g. letter recognition, spelling (Gathercole, Pickering, Knight, & Stegmann, 2004), phonological awareness (Berninger et al., 1992) for literacy and Arabic number knowledge, counting, magnitude understanding for mathematics (Geary, Hamson, & Hoard, 2000), as well as in general cognitive processes, which are involved in many learning situations (Gathercole, Pickering, Knight, et al., 2004). The ability to store and manipulate information in working memory (WM) is one of these general cognitive factors and is associated to scholastic achievement, such as writing (Bourke & Adams, 2003; Jarvis & Gathercole, 2003), reading (Gathercole, Brown, & Pickering, 2003; Jarvis & Gathercole, 2003; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012) and mathematical skills (Jarvis & Gathercole, 2003; McKenzie, Bull, & Gray, 2003; Noël, 2009; Noël, Seron, & Trovarelli, 2004; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011).

A large number of studies have pointed out the role of working memory throughout numerical development (see Raghubar, Barnes, & Hecht, 2010 for a review). In preschool, weak WM is associated with difficulties in early numeracy (Gersten, Jordan, & Flojo, 2005; Toll & Van Luit, 2013) with a slower learning of the counting string (Noël, 2009) and lower accuracy in solving simple additions (Noël, 2009; Rasmussen & Bisanz, 2005). For instance, 4-year-old children's accuracy in simple addition problems is related to the number of units held in WM to solve a given problem (Klein & Bisanz, 2000). In addition, weak WM when entering in primary school predicts the use of less mature calculation strategies and weaker accuracy in solving simple additions (Noël et al., 2004). Weak WM capacities have indeed often been observed in children presenting learning disabilities in mathematics (Geary, 2005) and differences in WM capacity distinguish between typically developing children and children with, or at risk of developing, mathematical learning disabilities (Andersson & Lyxell, 2007; Gathercole & Pickering, 2000b; Toll et al., 2011; Toll & Van Luit, 2013).

Baddeley and Hitch (1974) have defined WM as a system with a limited capacity allowing the temporary storage and manipulation of information. In their model, WM is composed of two slave systems, the phonological loop (PL) and the visuo-spatial sketchpad (VSSP), which are responsible for the temporary storage of verbal (PL) or visuo-spatial (VSSP) information. The third component is the central executive (CE) which handles the trade-off between the storage of information and simultaneous processing. In the present paper, the PL and the VSSP refer to the slave systems for, respectively verbal and visuo-spatial information, and the verbal CE and visuo-spatial CE refer to the ability to both maintain and manipulate verbal and visuo-spatial information, respectively. In 2000, Baddeley added a fourth component to his model: the episodic buffer which will not be addressed here as it has never been considered in numerical cognition studies. Several authors have investigated how each WM component is associated with numerical development. Several studies have shown that young children's (5-7 years old) CE abilities are closely related to mathematical performance assessed by a global counting (Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009) or math test (De Smedt et al., 2009). As concerns the slave systems, the VSSP seems to play a stronger role in young (preschool) children's math performance while older (primary school) children rely more on the PL (De Smedt et al., 2009; Holmes & Adams, 2006; McKenzie et al., 2003; Raghubar et al., 2010; Rasmussen & Bisanz, 2005; Titz & Karbach, 2014; van der Ven, van der Maas, Straatemeier, & Jansen, 2013).

As many of these studies are correlative in nature, no strong causal relationship can be drawn from them. To go further into this direction, some authors have developed training studies in which they boosted WM capacities and examined the impact of this increase on numerical abilities. Indeed, several studies indicated that WM capacities can be trained in children and adolescents (Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Van der Molen, Van Luit, Van der Molen, Klugkist, & Jongmans, 2010) as well as in preschoolers (Thorell, Lindqvist, Bergman-Nutley, Bohlin, & Klingberg, 2009) and the effects remain 3 (Klingberg et al., 2005; Van der Molen et al., 2010) to 6 (Holmes et al., 2009) and even 12 months later (Dunning et al., 2013). Some authors observed an impact of WM training on mathematics, measured by an academic test (Bergman-Nutley & Klingberg, 2014; Holmes & Gathercole, 2014), while others did not (Alloway, Bibile, & Lau, 2013; Dunning et al., 2013; Gray et al., 2012; Holmes et al., 2009; Karbach, Strobach, & Schubert, 2015). A few studies (K. I. E. Dahlin, 2013; Kanerva & Kyttala, 2016; Kroesbergen, Van't Noordende, & Kolkman, 2014; Kyttälä, Kanerva, & Kroesbergen, 2015; Passolunghi & Costa, 2016; Witt, 2011) have examined the impact of WM training on specific numerical processes. K. I. E. Dahlin (2013) has shown that 9-12 year-old children with attention deficits improved in several number tasks (completing logical series of numbers; giving the digit standing for the units, tens or hundreds in a number, drawing lines round items to group them; and on a drawing shading in 1/n of an item, e.g. chocolate bar) after 25 days of computerized training consisting of VSSP, PL and CE tasks. With 9- to 10-year-old participants, Witt (2011) showed that training verbal CE abilities through drill and strategy teaching during six weekly 15-minute session enhances CE and VSSP abilities as well as mental addition. To our knowledge, five studies have been done with preschoolers. Kroesbergen et al. (2014) have shown that training 5-year olds in tasks requiring the VSSP and the CE during eight 30-minute sessions enhances CE abilities as well as performance in counting, assessed by the Early Numeracy Test-Revised (Van Luit & Van de Rijt, 2008), and in a dot comparison task in which children have to select, among two sets, the one containing the larger amount of dots. Then, in Passolunghi and Costa (2016)'s study, 5-year-old children showed better performance in CE abilities and in a test (Early Numeracy Test; Van Luit et al., 1994) assessing logical operations (comparison, classification, seriation, ...) and counting after ten 60-minute sessions of PL, VSSP and CE games. On the contrary, Kyttälä et al. (2015) compared two training programs consisting of eight 30-minute sessions: one counting program and one program combining counting and WM (VSSP, PL and CE) and they showed that counting training is more efficient than the combined program to improve counting skills (Early Numeracy Test –R; Van Luit & Van de Rijt, 2008). Then, Kanerva and Kyttala (2016) showed that training 6-year-olds in one specific component of WM (PL, VSSP, verbal CE and visuo-spatial CE) with a computerized program during 10 sessions does not lead to any gain in WM nor in counting. In all these four studies (Kanerva & Kyttala, 2016; Kroesbergen et al., 2014; Kyttälä et al., 2015; Passolunghi & Costa, 2016), the effect of the intervention on preschoolers' numerical competences was measured by a global test, the Early Numeracy Test that focuses mainly on counting skills, as well as by a dot comparison task (Kroesbergen et al., 2014). More recently, we (Honoré & Noël, 2017) conducted a WM training study in which we aimed at examining the differential impact of WM training on specific numerical processes, including addition. However, we only observed a slight improvement of 5-6-year olds' CE abilities after 16 sessions of training targeting that memory component and we failed to observe any impact on numerical processes and arithmetic. It is possible that the failure to obtain any impact on numerical processes is due to the weak improvement measured in WM. In (Honoré & Noël, 2017), the WM training program was developed by the authors themselves and involved different verbal and visuo-spatial games that children played in small groups (n-back, updating tasks…). In the present study, we wanted to use a program that automatically adapts its difficulty level to the child's level of performance in order to maximize its efficacy. Furthermore, as the literature shows that visuo-spatial WM skills are particularly important in preschool age for numerical development, we opted for a program that targets the VSSP and visuo-spatial CE abilities. For these two reasons, we used the Cogmed WM Training program that has been proved to be efficient in several previous studies (K. I. E. Dahlin, 2011; Holmes et al., 2009; Klingberg et al., 2005; Klingberg et al., 2002; Thorell et al., 2009). We wanted to measure the impact of the intervention on numerical and arithmetical competence both in the short and medium (ten weeks later) terms.

To that aim, we compared the effects of the intensive adaptive version of the Cogmed WM training program to those of the demo non-adaptive version on WM (PL, VSSP and CE in verbal and in visuo-spatial modality) and on several numerical processes (counting, comparisons, number line and addition). Cogmed JM was used in the study as this is the version designed for preschoolers. Although recent meta-analyses question the effectiveness of Cogmed (Hulme & Melby-Lervag, 2012; Shipstead, Hicks, & Engle, 2012) and WM training in general (Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012), it is worth noting that most of the reviewed studies were done with older children and adults. However, according to Wass, Scerif, and Johnson (2012), cognitive training tends to yield larger effects when it is applied to young children. As the present training study concerned preschoolers, it is reasonable to address the following hypotheses: we first expected an impact of training on tasks tapping the VSSP and the visuo-spatial CE as these are the memory components trained in this specific WM training program. Second, we wanted to examine the relation between the different components of WM by assessing the possible training impact on tasks tapping the PL and the verbal CE. Some authors suggest that there would be less separation between the different components of WM before 8 years old (Hale, Bronik, & Fry, 1997) and that visuo-spatial processes are implicated in backward recall of information (see Berch, 2008). In addition, WM-training-related increase of activity has been observed in the intraparietal-prefrontal network (K. I. E. Dahlin, 2013; Olesen, Westerberg, & Klingberg, 2004; Westerberg & Klingberg, 2007) which would be multi-modal (Curtis & D'Esposito, 2003; Klingberg, Kawashima, & Roland, 1996; Linden, 2007). As a training effect is expected to transfer to other tasks or functions if they rely on the same neural network (Olesen et al., 2004), improvement could be observed in the slave systems or the central executive irrespective of the modality. On the contrary, other studies assert that the WM system already shows separate components at a young age (Alloway, Gathercole, & Pickering, 2006; Alloway, Gathercole, Willis, & Adams, 2004; Gathercole & Pickering, 2000a; Gathercole, Pickering, Ambridge, & Wearing, 2004). Similarly, some authors found higher within- than between-component correlations (e.g. Alloway et al., 2006; Noël, 2009) and a differential involvement of the verbal and VS components in addition solving (e.g. De Smedt et al., 2009; Noël, 2009; Rasmussen & Bisanz, 2005). Thus, if WM systems are not separated at preschool age, a training effect is expected in all WM tasks, irrespective of the modality. However, if WM is already divided into subcomponents responsible for verbal or visuo-spatial processing, the training program should only impact visuo-spatial tasks.

We then measured whether there would be transfer effects on numerical competences. As the program targets visuo-spatial WM (VSSP and visuo-spatial CE), the impact of training was especially expected on numerical abilities that are supposed to rely on visuo-spatial memory. So, we predicted that increase in VSSP performance might lead to improved performance in collection comparison, Arabic number comparison, number line positioning and additions. Indeed, it has been shown that VSSP skills are related to collection comparison (Xenidou-Dervou, De Smedt, van der Schoot, & van Lieshout, 2013) and Arabic number comparison (Vanbinst, Ghesquière, & De Smedt, 2015; Xenidou-Dervou et al., 2013). Moreover, young children's abilities in a simple arithmetic task are severely impaired by visuo-spatial interference (McKenzie et al., 2003) and, in children and adolescents, activation in the intra-parietal sulcus while performing a VSSP task predicts arithmetic performance two years later (Dumontheil & Klingberg, 2012). Then, although no current data is available on this point, the role of visuo-spatial competences in the mathematical field is probably to spatially represent and manipulate information, as in a mental number line (Bachot, Gevers, Fias, & Roeyers, 2005; Zorzi, Priftis, Meneghello, Marenzi, & Umilta, 2006; Zorzi, Priftis, & Umilta, 2002). Hence increased VSSP capacities could lead to higher accuracy in the positioning of Arabic numbers on a number line. Then, we also examined the impact of visuo-spatial WM training on counting skills, even though verbal counting development has been shown to mainly rely on the verbal memory system (both the PL and the verbal CE, see Noël, 2009). Two possibilities are considered. First, training effects are restricted to the trained modality because WM is composed of distinct components (Alloway et al., 2006) and no impact is therefore expected in the verbal-related-numerical skills. Second, WM is a global system and training effects are modality-independent (Hale et al., 1997; Westerberg & Klingberg, 2007), therefore transfer could appear, with a possible smaller effect, in verbal numerical task.

Effects of WM training on WM capacities were expected to be observed directly after training and to last weeks after. Regarding the numerical skills, training was expected to boost concurrent development and to show effects in the long term as children with improved WM abilities would be expected to benefit more from the various numerical activities in school and develop their numerical skills faster.

Method

Participants

Participants were recruited from a middle-class school in Walloon Brabant, Belgium. Children were all native French speakers except for one child whose mother tongue was Spanish but who spoke French fluently as she was living in a French environment since birth[i]. They were in their last (third) year of kindergarten. At this age, children do not receive formal mathematical education yet but teachers provide activities to help them develop their numerical skills (counting, recognition and writing of Arabic numbers, matching between Arabic numbers and quantities, number line…). One child did not complete the training program; therefore he was excluded from analyses and, due to school absences, two other participants were not tested at the follow-up. The sample consisted of 46 children, 26 boys and 20 girls (Age: M = 5 years 2 months; SD = 3.36 months) for pre- and post-test analyses and of 44 children, 25 boys and 19 girls (Age: M = 5 years 7 months; SD = 3.39 months) for follow-up analyses. Participants were randomly assigned to either the experimental group or the active control group (N = 23 in each group, 13 boys and 10 girls), and they were statistically equivalent in terms of age, $F(1,45) = 0.88$, $p = .353$. The study was approved by the ethics committee of the Psychological Science Research Institute.

Procedure

The study took place at school during school hours for a period of 7 weeks. Participants were pre-tested (T1) during the first week, they were then engaged in the training program during the next 5 weeks and post-tested (T2) the last week. Then, 10 weeks later, they were tested a third time for the follow-up (T3).

Training

Cogmed (Klingberg et al., 2005; Klingberg et al., 2002) is a computerized training program presented in the context of a fairground in which seven different attractions correspond to the training tasks. Basically, each task displays monsters distributed on the screen. When the participant is ready, he presses the space bar to make the monsters jump successively. Then, he is invited to click on each monster in the same order as they jumped. These tasks essentially involve the VSSP; but in two of them, the monsters move while jumping, requiring the participants to both maintain into short-term memory the order of the jumping monsters and update the location of each of them, which involves the CE. Hence, the VSSP and the visuo-spatial CE are the targets of this training program. Every training day, children had to complete three out of the seven games. In the experimental group, difficulty was adjusted by increasing or decreasing the number of stimuli to remember (jumping monsters) according to prior performance of the child; training lasted for approximately 20 minutes. Children received a virtual sea star for every correct trial and, at the end of the session, these rewards were exchanged for a virtual fish in an aquarium. Thus, progressing through training, each participant's aquarium gradually filled.

As claimed by Green, Strobach, and Schubert (2014), the choice of an adequate control group is a fundamental issue in training studies. The authors recommend an active control group which includes all the possible causes of improvement that are of no interest. Thus, in the present study, we chose an active control group; both the experimental and the control groups played Cogmed daily during five weeks. The only difference lied in the fact that the games were adaptive in the experimental group; the participants played at a difficulty level close to their capacity whereas the control group stayed at the initial low level as it was done in several other studies (Dunning et al., 2013; Holmes et al., 2009; Klingberg et al., 2002). This type of active control groups has the advantage of incorporating most of the components of the trained tasks, but the only risk concerns the possible lack of motivation (Green et al., 2014). In the control group, children stayed at a low level (one or two items to remember) and playing time was approximately 10 minutes. Rewards were also exchanged for a virtual fish at the end of each session, which helps to avoid the possible lack of motivation and arousal in the control group (Green et al., 2014).

Participants played the games in groups of five in a quiet room at school. They each sat in front of a computer equipped with headphones (for instructions and sounds of the monsters) and a mouse. The experimenter did not help the children to perform the tasks, but was present to help with technical materials (e.g. computer, mouse, headphones) and to motivate the children.

Baseline

Twelve tasks were administered both the week before and the week after the training period; six of them assessed WM abilities (forward word span, backward word span, Corsi, Odd One Out, updating and categospan) and the six others tapped numerical cognition (counting, elaboration of the counting string, collection comparison, Arabic number comparison, number line positioning and addition)[ii]. The tasks were presented in the following order to balance difficulty and maintain motivation: forward word span, collection comparison, updating, counting, elaboration of the counting string, Odd One Out, Arabic number comparison, categospan, number line, Corsi, addition and backward word span). The follow-up consisted of six of these tasks, presented in the following order: Arabic number comparison, categospan, number line, Odd One Out, additions, Corsi. This last testing session was reduced due time constraint at the end of the school year.

Working memory tasks — *Phonological loop.* This slave system was measured with a forward word span used by Noël (2009). The examiner presented a series of one-syllable words to the child at the rate of one per second and asked him or her to repeat them in the order of presentation. The experimenter first presented lists of two words, then three, then four, and so on. There were three trials at each level of difficulty. If the child failed at two out of the three trials, the task was stopped. The measure was a corrected span, corresponding to the longest length for which at least two trials were correctly repeated, plus .5 if one trial of the next series length was successfully achieved, was used as the dependent variable.

Visuo-spatial sketchpad. To assess this second slave system, we used the Corsi. In this task, nine identical cubes glued on a board (Farrell Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006) were placed between the experimenter and the child. The experimenter touched a series of cubes of increasing length and the child had to point out the same cubes in the same order of presentation. Three trials per length were presented to the child and stopping rule was the same as for the forward word span. The corrected span was used as the dependent variable.

Central executive. Four tasks were proposed to evaluate the CE, two using verbal material and two using visually-presented materials. First, in the backward word span, the same materials and procedure as in the forward word span were used but children are asked to repeat the words in the reverse order. If the complexity of this task can be questioned in adults, it is very different in pre-schoolers. Indeed, as observed by Noël (2009), about half of four-year olds failed to even understand the task while five-year olds can deal with it although it is quite effortful. Second, we used the categospan, developed by Noël (Noël, 2009). It is a categorization task in which one-syllable words of animals or food were orally presented to the child, who had to repeat them by category, starting with the animals and ending with the food items. Third, we developed the Odd One Out task, derived from the odd-man-out task (Russell, Jarrold, & Henry, 1996). On a computer, the child was presented with series of vertical rectangles, arranged from left to right, each rectangle containing three white squares (see Figure 1). When the child was attentive, the experimenter pressed the space bar and a circle appeared in each square of the first rectangle. One of the circles was different from the others and the child had to point the odd one. Once the child had answered, the experimenter pressed the space bar once to make the circles disappear and a second time to make the circles appear in the next rectangle. At the end of the trial, the child was asked to show the position of each odd circle. The task started with two rectangles and then, depending on the child's performance, the number of rectangles increased. For these three tasks, the same procedure and dependent variable were used: there were three trials per length and a corrected span was calculated.

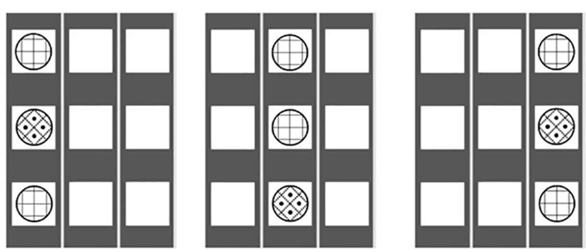

Figure 1. Odd One Out task.

Fourth, an updating task (Figure 2) was developed, the musical chair task, in which children were presented with three chairs on a computer screen, using Power Point; the middle chair was brown while the two others were blue. The experimenter said *"Animals are playing a sort of 'musical chairs'. Now you see three animals, each sitting on one chair, but they are going to move from their chair to the one on their left. So, this animal* [pointing at the one on the left blue chair] *is going to disappear, this one* [pointing at the one on the middle brown chair] *is going on this chair* [pointing at the left blue chair], *this one is going on this chair* [pointing at the middle brown one] *and another animal is coming from there* [pointing at the right side of the screen] *and going on this chair* [pointing at the right blue chair]. *You have to tap on the table each time the animals sitting on the blue chairs are identical"*. In other words, the child had to identify if the new animal (coming from the right side of the screen and going on the right blue chair) was the same as the n-2 animal (situated on the left blue chair). There are five animals in total and the child was invited to name them before starting the task. During twelve practice trials, all animals were visible and there were two n-2 items (targets). Then, the test trials were divided into two parts. In the first part, the animal sitting on the left blue chair was hidden behind a curtain and, in the second part, both the left and the middle animals were hidden behind the curtain. In each part, there were 6 targets (n-2), 6 near distractors (n-3) and 6 far distractors (n-8/9 for the first part and n-9/10 for the second part). The percentage of correct responses (% CR) was recorded.

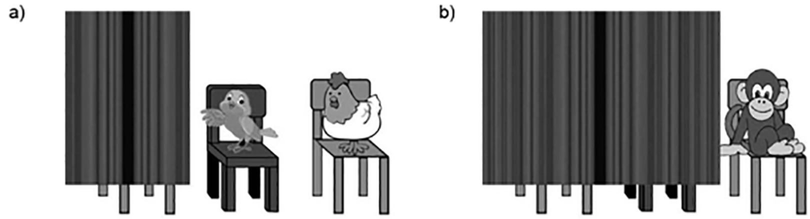

Figure 2. Updating task: first (a) and second (b) parts.

Numerical tasks — *Counting.* The child was asked to count out loud as high as he could; he/she was stopped if he made a mistake. The highest number produced in a correct sequence was used as the dependent variable.

Elaboration of the counting string. A series of tasks, developed by Noël (2009), were presented to the child who was asked to (a) count from 5 and then from 7 (the child was stopped when 10 was reached), (b) count from 5 to 9 and then from 4 to 8, and (c) count two steps from 5 and then from 8. For these last two tasks, the experimenter explained the instructions as follows: *"Imagine a frog jumping. If it jumps three times it does 'one – two – three' and if it jumps three times, starting at two, it does 'two – three – four'. Now it is your turn, the frog jumps two times starting at three, so it does …?".* The % CR was used as the dependent variable.

Collection comparison. An adaptation of Rousselle, Dembour, and Noël (2013)'s task was used. Children were presented with two boxes on a computer screen, using E-prime, each containing a collection of puzzle pieces and asked to select the larger collection. To prevent children from relying on non-numerical parameters, perceptual variables were controlled (see Rousselle et al., 2013 for details). First, the external perimeter was equated for all trials. Second, congruent and incongruent trials were built (half of each). In congruent trials, the larger collection in number also had the larger density and surface, whereas in incongruent trials, the larger collection in number had the smaller density and surface. The amount of puzzle pieces varied from 5 to 18, i.e. above the subitizing range. Six practice pairs of sets differing by a ratio of 1:3 familiarized children with the task. The test trials were pairs of sets differing by ratios of 1:2, 2:3, 3:4, 4:5, 5:6, 6:7 and 7:8. There were two pairs per ratio (7-14 and 8-16; 6-9 and 10-15; 6-8 and 12-16; 8-10 and 12-15; 5-6 and 10-12; 6-7 and 12-14; 7-8 and 14-16) and each pair was presented four times, varying along order (ascending or descending) and condition (congruent or incongruent), resulting in 56 items. Items were presented in a fixed random order, respecting five criteria: maximum 3 consecutive same-answer items, maximum 3 consecutive same-condition items, maximum 2 consecutive same-ratio items, no consecutive items of identical pair and the two first pairs were 1:2-ratio items. The % CR was used as the dependent variable.

Arabic number comparison. This task invited the child to select the larger of two Arabic numbers (from 1 to 19; 20 was excluded because of its physical dissimilarity to other numbers) presented simultaneously on a computer screen, using E-prime. Stimuli varied according to two numerical sizes, small (1-9) and large (10-19) and two numerical distances, close (1) and far (3), resulting in four conditions (far-small, close-small, far-large, close-large), containing each 6 different pairs, presented in two orders (ascending and descending) for a total of 48 items (6 pairs x 2 orders x 4 conditions). All the stimuli were presented in a fixed random order, according to four criteria: maximum 3 consecutive same-answer items, maximum 2 consecutive same-condition items, no consecutive items of identical pair and the two first items corresponded to far-small pairs. The % CR was used as the dependent variable.

Number line positioning. In this task, children were invited to position an Arabic number on a horizontal non-graduated number line with 1 and 20 at the left and right sides. For each number to place (from 2 to 19), a new number line was presented. To measure the precision of the child's positioning on the number line, we calculated the median Percent Absolute Error (PAE = [(estimate – correct response) / scale of estimate] X 100) which was used as the dependent variable.

Additions. In this task, developed by Noël (2009), children were invited to solve 13 additions (4 ties: 2+2, 3+3, 4+4 and 5+5 and nine other problems: 2+3, 2+4, 2+5, 2+8, 3+4, 3+5, 3+5, 4+5, 4+6). For each problem, the child was presented with a drawing of apples corresponding to the first operand and tokens were at his/her disposal. The experimenter said to the child *"Here are* [number of apples] *apples. If you add* [second operand] *apples, how many would there be in total?"*. The child's answer, use of drawing, tokens or fingers to count as well as the counting strategy (counting all, counting on, counting min and mental strategy) were recorded. Each item was score 0 or 1 and, when the item was succeeded, a strategy score was attributed. The % CR and was used as dependent variable.

Results

Training Check

The training program is designed to be played every school day during five weeks, resulting in 25 sessions. However, due to school activities and children's absences, this number of session was not possible. Most children had almost 20 (experimental group: M = 19.26; SD = 2.3 and control group: M = 20.65; SD = 1.72). The program calculates a starting (second and third days of the training period) and a maximum (two best days of the training period) scores and on this basis, an evolution score is generated (maximum score – starting score). The mean evolution score is expected to be around 24 and should be between 14 and 32 (Cogmed, 2011). In our study, the mean evolution score was 20.43 (SD = 6.48). At first, all children had fun playing with these games; but from the third training week, their motivation started to decrease as the games were always the same and it was becoming increasingly difficult. So, they received a few rewards to maintain their motivation.

Analyses

Validity of the Tasks

First, we examined the reliability of our tasks by computing test-retest (T1-T2) correlations for all baseline tasks. Except for the updating task, all test-retest correlations were significant (see Table 1).

Table 1

Age and Performance in Each Baseline Task at T1, T2 and T3 for Each Group

	Age	Forward word span	Corsi	Backward word span	Odd One Out	Categospan	Counting	Elaboration of the counting string	Collection comparison	Arabic number comparison	Number line	Additions
Test-retest		*r*(46) = .47	*r*(46) = .36	*r*(46) = .32	*r*(46) = .56	*r*(46) = .57	*r*(46) = .65	*r*(46) = .35	*r*(46) = .34	*r*(46) = .80	*r*(46) = .76	*r*(46) = .73
correlation		($p = .001$)	($p = .015$)	($p = .030$)	($p < .001$)	($p < .001$)	($p < .001$)	($p = .019$)	($p = .020$)	($p < .001$)	($p < .001$)	($p < .001$)
Experimental group												
T1	5;6 y.o. ± 3 m.	3.18 ± 0.80	3.63 ± 0.57	2.13 ± 0.61	3.02 ± 0.63	2.76 ± 0.80	28.30 ± 12.99	35.51 ± 32.30	61.10 ± 7.06	73.10 ± 17.24	14.75 ± 11.73	32.11 ± 29.12
T2		3.39 ± 0.45	4.30 ± 0.86	2.39 ± 0.45	3.58 ± 0.69	3.30 ± 0.54	33.17 ± 14.88	59.42 ± 33.27	63.28 ± 5.79	80.71 ± 17.86	12.96 ± 8.57	45.48 ± 30.76
T3			3.88 ± 0.76		3.52 ± 0.62	3.07 ± 0.60				84.82 ± 15.98	10.46 ± 4.93	56.41 ± 32.30
Control group												
T1	5;7 y.o. ± 3 m.	3.35 ± 0.49	3.76 ± 0.65	2.35 ± 0.46	3.17 ± 0.56	2.96 ± 0.85	26.74 ± 10.15	44.93 ± 34.24	61.88 ± 7.89	72.64 ± 17.29	17.37 ± 9.94	39.13 ± 31.11
T2		3.35 ± 0.51	3.98 ± 0.63	2.48 ± 0.44	3.24 ± 0.71	3.33 ± 0.58	30.96 ± 18.1	52.90 ± 32.82	61.80 ± 6.27	74.64 ± 17.92	16.45 ± 8.94	46.82 ± 29.05
T3			3.70 ± 0.58		3.46 ± 0.8	3.26 ± 0.72				84.06 ± 15.02	15.09 ± 7.89	57.19 ± 27.22

Note. Measures are expressed in corrected span for forward/backward word spans, Corsi, Odd One Out and categospan; in percentage of correct responses for elaboration of the counting string, Arabic number/collection comparison and additions; in highest number reached for counting; and in PAE for the number line.

Next, for the tasks we developed (updating, Arabic number comparison and number line positioning), internal consistency was assessed with Cronbach's alphas. For the updating task, these indexes were low (T1: $\alpha = 0.28$ and T2: $\alpha = 0.10$) but they were very good for the Arabic number comparison (T1: $\alpha = 0.88$ and T2: $\alpha = 0.91$) and for the number line positioning (T1: $\alpha = 0.85$ and T2: $\alpha = 0.84$) tasks. Given the low validity of the updating task, its results were no longer considered. Finally, the validity of Arabic number comparison and number line positioning was also tested by verifying the presence of expected difficulty effects at T1. For Arabic number comparison, an ANOVA on the % CR with size (small and large) and distance (far and close) as factors revealed that performance was higher for small (78.62 ± 16.16%) than for large (67.12 ± 20.15%) numbers, $F(1,45) = 35.99$, $p < .001$, and for far (77.45 ± 17.22%) than for close (73.10 ± 17.08%) number pairs, $F(1,45) = 4.06$, $p = .050$ as it is typically expected for this type of task (Alloway et al., 2006). Finally, for the number line positioning task, the analysis on PAE with the size as factor revealed a higher precision for small (10.97 ± 11.19%) than for large (23.29 ± 14.13%) numbers, $F(1,45) = 36.83$, $p < .001$.

Comparison of the Groups at T1

The groups were equivalent on each baseline task ($F(1,45) = 1.86$, $p = .179$ for backward word span and *F*s < 1 for the remaining tasks). See Table 1 for descriptive statistics.

Effect of Training

Three main questions were addressed. (1) Is this training program, aiming to increase visuo-spatial WM efficient? (2) Does it transfer to performance in verbal memory tasks? (3) Does this memory-training program have an impact on children's numerical development? And if yes, on which specific numerical tasks? To address these three questions, targeted multivariate analyses of variance (MANOVA) with Time (T1: pretest and T2: direct post-test) as within-subject factor and Group (experimental and control) as a between-subject factor were calculated. The first one was conducted on visuo-spatial WM measures (Corsi and Odd One Out); the second one on verbal WM measures (forward word span, backward word span and categospan) and the last one on numerical tasks (counting, elaboration of the counting string, collection comparison, Arabic number comparison, number line and additions). Then, to assess the stability of the effects on the middle-term (T3), repeated-measures MANOVAs were run on visuo-spatial WM measures (Corsi and Odd One Out) and on numerical tasks (Arabic number comparison, number line and additions) with Time (T2 and T3) and Group as factors. For verbal WM, as only the categospan was used in T3, a repeated-measures ANOVA was computed. Univariate analyses were also conducted separately for each baseline task to check for any possible training effect.

Immediate effect of training — *Visuo-spatial working memory measures.* The MANOVA showed that the main effect of time was significant, $F(1,44) = 34.36$, $p < .001$, $\eta^2 = 0.439$. There was also a significant effect of task, $F(1,44) = 50.12$, $p < .001$, $\eta^2 = 0.532$, with higher performance in Corsi than Odd One Out. The effect of group was not significant, $F(1,44) = 0.47$, $p = .498$, $\eta^2 = 0.010$. More importantly, the Time x Group interaction effect was significant, $F(1,44) = 13.53$, $p = .001$, $\eta^2 = 0.235$, revealing a significant training effect on visuo-spatial WM measures. This Time x Group interaction was significant for both the Corsi (Figure 3) and the Odd One Out (Figure 4); see Table 2 for the univariate analyses. For both tasks, contrasts with Bonferroni adjustment revealed that the experimental group significantly improved from pre- to post-test, $t(44) = 4.22$, $p < .001$, $\eta^2 = 0.289$ for Corsi and $t(44) = 4.71$, $p < .001$, $\eta^2 = 0.336$ for Odd One Out, while the control group did not, respectively, $t(44) = 1.36$, $p = .360$, $\eta^2 = 0.041$ and $t(44) = 0.55$, $p = 1$, $\eta^2 = 0.007$.

Table 2

Results of the ANOVAs Testing for Immediate Training Effects on Each WM Baseline Task

Task	Effect of time	Effect of group	Effect of interaction
Corsi	$F(1,44) = 15.63$, $p < .001$, $\eta^2 = 0.262$	$F(1,44) = 0.34$, $p = .565$, $\eta^2 = 0.008$	$F(1,44) = 4.10$, $p = .049$, $\eta^2 = 0.085$
Odd One Out	$F(1,44) = 13.84$, $p = .001$, $\eta^2 = 0.239$	$F(1,44) = 0.31$, $p = .579$, $\eta^2 = 0.007$	$F(1,44) = 8.68$, $p = .005$, $\eta^2 = 0.165$
Forward word span	$F(1,44) = 1.37$, $p = .247$, $\eta^2 = 0.030$	$F(1,44) = 0.18$, $p = .677$, $\eta^2 = 0.004$	$F(1,44) = 1.37$, $p = .247$, $\eta^2 = 0.030$
Backward word span	$F(1,44) = 5.15$, $p = .028$, $\eta^2 = 0.115$	$F(1,44) = 1.67$, $p = .203$, $\eta^2 = 0.37$	$F(1,44) = 0.57$, $p = .453$, $\eta^2 = 0.013$
Categospan	$F(1,44) = 20.51$, $p < .001$, $\eta^2 = 0.318$	$F(1,44) = 0.36$, $p = .552$, $\eta^2 = 0.008$	$F(1,44) = 0.74$, $p = .393$, $\eta^2 = 0.017$

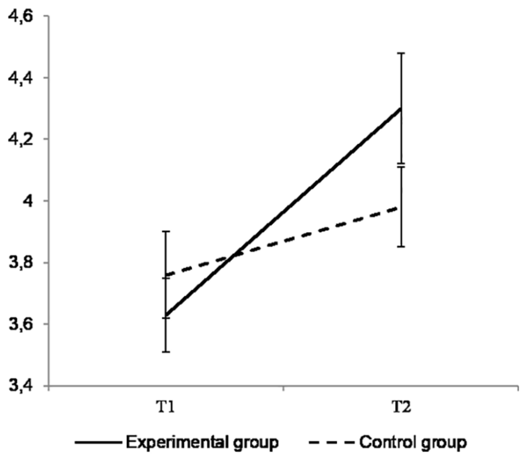

Figure 3. Interaction between time (T1 and T2) and group (Experimental and Control) for the span measure in the Corsi task. Error bars represent standard errors.

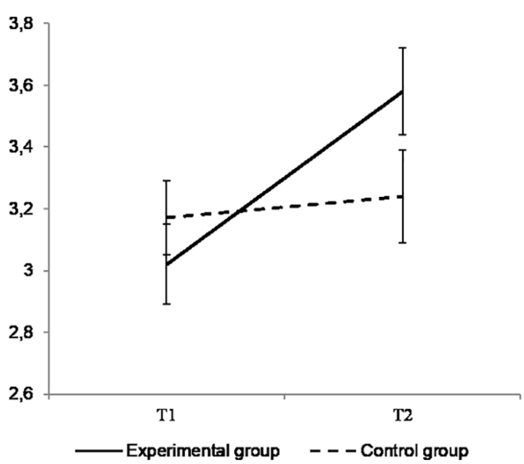

Figure 4. Interaction between time (T1 and T2) and group (Experimental and Control) for the span measure in the Odd One Out task. Error bars represent standard errors.

Verbal working memory. The MANOVA indicated a significant effect of time, $F(1,44) = 18.02$, $p < .001$, $\eta^2 = 0.291$, and a significant effect of task, $F(2,88) = 71.86$, $p < .001$, $\eta^2 = 0.620$; performance was higher in forward word span (3.32±0.49) than in categospan ($p = .016$) which was better performed (3.09 ± 0.61) than backward word span (2.34 ± 0.40, $p < .001$)[iii]. The effect of group was non-significant, $F(1,44) = 0.89$, $p = .350$, $\eta^2 = 0.020$ and the Time x Group interaction effect was also non-significant, $F(1,44) = 2.07$, $p = .157$, $\eta^2 = 0.045$. The univariate tests of each verbal measure revealed non-significant interaction effects (see Table 2). There was thus absolutely no impact of training on verbal WM tasks.

Numerical tasks. The MANOVA indicated a significant effect of time $F(1,44) = 6.64$, $p = .013$, $\eta^2 = 0.131$, and a non-significant effect of group, $F(1,44) = 0.23$, $p = .636$, $\eta^2 = 0.005$. The Time x Group interaction effect was non-significant, $F(1,44) = 0.06$, $p = .804$, $\eta^2 = 0.001$. The effect of task was significant but it is not detailed here as the measures of each task were too different to be worth being compared (i.e. total success, % CR, PAE). The results of the repeated-measures univariate analysis of variance (Table 3) indicated a marginal interaction effect in Arabic number comparison (Figure 5), a significant improvement being observed in the experimental group only, $t(44) = 3.36$, $p = .002$, $\eta^2 = 0.204$ ($t(44) = 0.88$, $p = .384$, $\eta^2 = 0.017$ for the control group). A very slight effect of training was thus observed in Arabic number comparison.

Table 3

Results of the ANOVAs for the Immediate Training Effects on Numerical Baseline Tasks

Task	Effect of time	Effect of group	Effect of interaction
Counting	$F(1,44) = 5.87$, $p = .020$, $\eta^2 = 0.118$	$F(1,44) = 0.25$, $p = .620$, $\eta^2 = 0.006$	$F(1,44) = 0.03$, $p = .863$, $\eta^2 = 0.001$
Elaboration of the counting string	$F(1,44) = 8.36$, $p = .006$, $\eta^2 = 0.160$	$F(1,44) = 0.03$, $p = .858$, $\eta^2 = 0.001$	$F(1,44) = 2.09$, $p = .155$, $\eta^2 = 0.045$
Collection comparison	$F(1,44) = 0.83$, $p = .367$, $\eta^2 = 0.019$	$F(1,44) = 0.05$, $p = .833$, $\eta^2 = 0.001$	$F(1,44) = 0.96$, $p = .333$, $\eta^2 = 0.021$
Arabic number comparison	$F(1,44) = 8.99$, $p = .004$, $\eta^2 = 0.170$	$F(1,44) = 0.44$, $p = .512$, $\eta^2 = 0.010$	$F(1,44) = 3.07$, $p = .087$, $\eta^2 = 0.065$
Number line	$F(1,44) = 3.71$, $p = .061$, $\eta^2 = 0.078$	$F(1,44) = 1.17$, $p = .285$, $\eta^2 = 0.026$	$F(1,44) = 2.16$, $p = .149$, $\eta^2 = 0.047$
Additions	$F(1,44) = 10.65$, $p = .002$, $\eta^2 = 0.195$	$F(1,44) = 0.26$, $p = .615$, $\eta^2 = 0.006$	$F(1,44) = 0.78$, $p = .383$, $\eta^2 = 0.017$

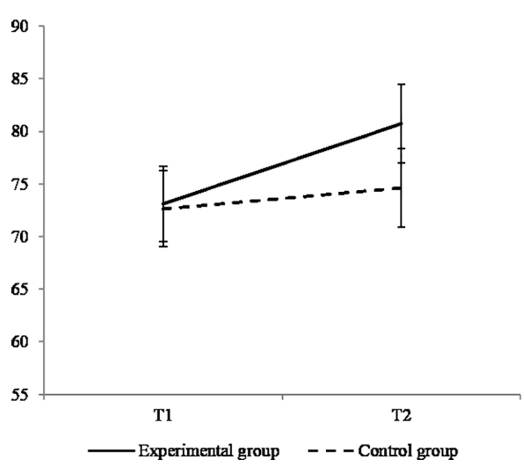

Figure 5. Interaction between time and group for percentage of correct responses in the Arabic number comparison task. Error bars represent standard errors.

Correlational analyses revealed that the improvement in Arabic number comparison significantly correlated with improvement in Corsi, $r(46) = .57$, $p < .001$, but not in Odd One Out, $r(46) = .10$, $p = .506$, indicating that this performance increase trend is related to VSSP improvement.

Training effects after ten weeks — *Visuo-spatial WM.* The MANOVA for visuo-spatial WM indicated a significant effect of time, $F(1,42) = 5.65$, $p = .022$, [INSERT FIGURE 006]^2 = 0.119, a non-significant effect of group, $F(1,42) = 8.85$, $p = .181$, $\eta^2 = 0.042$, and a marginal Time x Group interaction effect, $F(1,42) = 3.24$, $p = .079$, $\eta^2 = 0.072$; contrasts with Bonferroni correction indicated a significant decrease of performance (see Table 1 for descriptive statistics) in the experimental group, $t(42) = 3.84$, $p < .001$, $\eta^2 = 0.260$, and not in the control group, $t(42) = 1.15$, $p = .516$, $\eta^2 = 0.030$. The results of the univariate tests are displayed in Table 4 and revealed no significant Time x group interaction effect. The immediate training effect observed in visuo-spatial WM was not sustained 10 weeks later.

Table 4

Results of the ANOVAs Testing for Long-Term Effect for Each WM Task

Task	Effect of time	Effect of group	Effect of interaction
Corsi	$F(1,42) = 11.05$, $p = .002$, $\eta^2 = 0.208$	$F(1,42) = 1.48$, $p = .230$, $\eta^2 = 0.034$	$F(1,42) = 0.24$, $p = .625$, $\eta^2 = 0.006$
Odd One Out	$F(1,42) = 0.41$, $p = .527$, $\eta^2 = 0.010$	$F(1,42) = 1.35$, $p = .252$, $\eta^2 = 0.031$	$F(1,42) = 2.39$, $p = .129$, $\eta^2 = 0.054$

Verbal WM. The main effects of time, $F(1,42) = 2.54$, $p = .119$, $\eta^2 = 0.057$, and group, $F(1,42) = 0.58$, $p = .452$, $\eta^2 = 0.014$, as well as the interaction effect between time and group, $F(1,42) = 0.61$, $p = .440$, $\eta^2 = 0.014$, were non-significant. No further effect of training was thus observed on verbal WM.

Numerical tasks. The repeated-measures MANOVA indicated a significant main effect of time, $F(1,42) = 18.68$, $p < .0001$, $\eta^2 = 0.308$, and a non-significant effect of group, $F(1,42) = 0.07$, $p = .798$, $\eta^2 = 0.002$. The interaction effect between time and group was non-significant either, $F(1,42) = 0.16$, $p = .696$, $\eta^2 = 0.004$. The ANOVAs on each numerical measure (Table 5) did not indicate any significant Time x Group interaction effect. The marginal training effect observed on Arabic number comparison did not last on the long term.

Table 5

Results of the ANOVAs of the Long-Term Effects on Numerical Baseline Tasks

Task	Effect of time	Effect of group	Effect of interaction
Arabic number comparison	$F(1,42) = 16.14$, $p < .001$, $\eta^2 = 0.128$	$F(1,42) = 0.49$, $p = .486$, $\eta^2 = 0.012$	$F(1,42) = 2.29$, $p = .138$, $\eta^2 = 0.052$
Number line	$F(1,42) = 0.64$, $p = .430$, $\eta^2 = 0.015$	$F(1,42) = 7.99$, $p = .007$, $\eta^2 = 0.160$	$F(1,42) = 0.08$, $p = .775$, $\eta^2 = 0.002$
Additions	$F(1,42) = 15.06$, $p < .001$, $\eta^2 = 0.264$	$F(1,42) = 0.03$, $p = .867$, $\eta^2 = 0.001$	$F(1,42) = 0.06$, $p = .813$, $\eta^2 = 0.001$

Discussion

The aim of the current study was to assess, in preschoolers, the impact of a WM training program on WM abilities and, more importantly, to examine the possible impact of improved WM on numerical development. Indeed, WM abilities are very important for learning activities i.e. writing (Bourke & Adams, 2003; Jarvis & Gathercole, 2003), reading (Jarvis & Gathercole, 2003; Loosli et al., 2012) or mathematics (Jarvis & Gathercole, 2003; McKenzie et al., 2003; Noël, 2009; Noël et al., 2004; Toll et al., 2011). If we were able to find training programs that could enhance children's WM capacities and help them in their current learning, this could possibly lead to major positive cascading effects on the school disciplines. In this specific study, we examined the possible impact of such training in the very beginning of number skills learning at preschool. Although other studies have already examined working-memory-training effects on numerical development, the present one contributes to the literature with the use of a control condition very similar to the experimental one, the will to assess the effects of training on different numerical processes and to evaluate the longevity of the effects.

To this end, 23 preschoolers were daily trained with a computerized visuo-spatial WM intervention (Cogmed) for a period of 5 weeks. Their performances in WM as well as in numerical processing and arithmetic were assessed just before, just after and 10 weeks after the intervention; and were compared to those of 23 peers who were involved for the same number of sessions with the same game, except that it was not adaptive and did not increase in difficulty.

First of all, we expected a training effect on the trained processes, i.e. VSSP and visuo-spatial CE which is what we observed: children in the experimental group significantly improved their VSSP (Corsi) and visuo-spatial CE (Odd One Out) abilities, compared to the control group. The effect sizes were medium for the Corsi and large for the Odd One Out. These results are in line with several studies which showed that it is possible to train WM in adults (E. Dahlin, Nyberg, Backman, & Neely, 2008; Olesen et al., 2004; Westerberg & Klingberg, 2007), in children (Bergman-Nutley & Klingberg, 2014; K. I. E. Dahlin, 2013; Dunning et al., 2013; Gray et al., 2012; Holmes et al., 2009; Klingberg et al., 2005; Klingberg et al., 2002; Van der Molen et al., 2010) as well as in preschoolers (Honoré & Noël, 2017; Kroesbergen et al., 2014; Passolunghi & Costa, 2016; Thorell et al., 2009).

However, no effect was observed on the PL or the verbal CE; the effects were therefore restricted to the trained modality. This is in contradiction with the assumption that verbal and visuo-spatial systems of WM would not be two clearly separate systems in young children (Hale et al., 1997) and with the results of some studies showing a transfer effect of visuo-spatial WM training to the PL and verbal CE in preschoolers (Thorell et al., 2009) and to the PL in adolescents with mild to borderline intellectual disabilities (Van der Molen et al., 2010). Instead, these results are in line with the view that separate components of the short-term memory system can already be distinguished at a young age and that training effects are specifically observed on the trained component (Alloway et al., 2006; Gathercole, Pickering, Ambridge, et al., 2004).

As concerns numerical development, it is first important to note that most competences assessed in the baseline are sensitive to change over the time period considered (from T1 to T2), as the effect of time was significant for all numerical tasks, except for the collection comparison and the number line tasks. This means that the time window considered here is a sensitive period where children develop their abilities to count, to add and to access the magnitude of Arabic digits.

As regards the effect of WM training on these numerical skills, the MANOVA did not show any significant result, suggesting no training effect. Nevertheless, the univariate analyses indicated that performance in one of the tasks only, the Arabic number comparison, tended to increase more in the experimental than in the control group; and participants who improved more in VSSP showed more improvement in Arabic number comparison, as shown by the correlation between improvement in Arabic number comparison and improvement in Corsi. These results suggest that the slight enhancement in comparing Arabic numbers can be attributed to the training effect in VSSP. As demonstrated by Xenidou-Dervou et al. (2013) and Vanbinst et al. (2015), symbolic magnitude processing correlates with VSSP abilities. In addition, Kroesbergen et al. (2014) attribute the relation between visuo-spatial WM and early numeracy to the visuo-spatial nature of numerical representations. Indeed, math achievement relies on visuo-spatial processing (Raghubar et al., 2010) and number symbols are connected to their corresponding quantity via a spatial mapping (Holloway & Ansari, 2009) which is related to visuo-spatial WM (Bachot et al., 2005; Herrera, Macizo, & Semenza, 2008).

However, there was no impact of improved visuo-spatial WM on other numerical measures. For some of the task, this result could be explained by the fact that they are mainly verbal tasks. In particular, Noël (2009) has shown that counting skills are more related to verbal than visuo-spatial WM. As the training program failed to improve verbal WM, it is not surprising that related learning (i.e. counting and elaboration of the counting string) was not enhanced. This failure to find any training effect was more unexpected for the collection comparison and the number line tasks in which the role of the VSSP could be expected based on the literature (Kroesbergen et al., 2014; Xenidou-Dervou et al., 2013). Nonetheless, it should be noted that performance in these tasks did not show a significant increase over the time period considered. The absence of evolution in collection comparison is in accordance with Halberda and Feigenson (2008)'s findings suggesting no clear evolution of the ANS acuity from 5 to 6 years old. Thus, if these skills do not develop at this time, no training-related effect can be expected. Finally, no effect was observed in the addition task although performance did increase during this time period and previous research has shown that, to solve a problem, children mainly hold its representation in visuo-spatial memory (McKenzie et al., 2003).

Then we considered the possible middle-term effects of this training program. The impact we observed just after the intervention period in VSSP and visuo-spatial CE as well as in digit comparison vanished 10 weeks later. Although some studies have found long-lasting effects on WM (Dunning et al., 2013; Holmes & Adams, 2006; Klingberg et al., 2005; Van der Molen et al., 2010), these are not consistent in the literature; effects on verbal WM seem not to be sustained in the long term whereas impact on visuo-spatial WM may last a little longer but this issue has been examined by a few studies only (see Melby-Lervåg & Hulme (2013) for a review). Among the Cogmed studies, five have examined and observed long-term effects on WM (K. I. E. Dahlin, 2011, 2013; Dunning et al., 2013; Holmes et al., 2009; Klingberg et al., 2005), but two of them did not have a control group (K. I. E. Dahlin, 2011; Holmes et al., 2009), and they all concerned older children (7-12 years old). The present study is thus the first to test the possible long-term effects of WM training with preschoolers and our data suggest that they vanish within 10 weeks after training.

In summary, although many studies show the importance of WM capacities on cognitive development, including numerical development and more and more studies are conducted to develop appropriate programs that would enhance these WM capacities, the WM program used here did not yield satisfying effects in preschoolers. Indeed, most of the WM training studies with preschoolers, like the present one, observed an impact on the trained process (Kroesbergen et al., 2014; Passolunghi & Costa, 2016; Thorell et al., 2009). Regarding close-transfer effects, data are unclear; unlike Thorell et al. (2009), who showed a transfer effect to another modality, we did not observe improvement in verbal WM after visuo-spatial WM training and no other author has examined such a transfer effect. As concerns numerical abilities, the impact, if any, is very weak. Among the five studies (Honoré & Noël, 2017; Kanerva & Kyttala, 2016; Kroesbergen et al., 2014; Kyttälä et al., 2015; Passolunghi & Costa, 2016) which assessed a possible impact on young children's numerical skills, one of them did not find any transfer effect to numerical or arithmetical skills (Honoré & Noël, 2017), two of them failed to find an impact on counting (Kanerva & Kyttala, 2016; Kyttälä et al., 2015), another observed a significant improvement in counting and collection comparison (Kroesbergen et al., 2014) and the last one in counting

(Passolunghi & Costa, 2016). For our part, we observed a small tendency to improvement in Arabic number comparison. Different reasons for the small (or null) result should be considered. First, preschool children might be too young; indeed, Kanerva and Kyttala (2016) suggest that young children do not benefit from WM training because training-related effects with older children are explained by enhanced strategies (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010), which preschool children might not be able to develop and use. It is also possible that the improvement we observed in VSSP and visuo-spatial CE was not associated with higher numerical performance because children were not receiving formal mathematical education, although they were presented with several playful activities at school that aim to develop their numerical skills such as counting or reading Arabic digits. Studies with older children (Bergman-Nutley & Klingberg, 2014; K. I. E. Dahlin, 2013) seem a little more promising maybe because participants are spending hours each day learning mathematics. Concerning Kroesbergen et al. (2014) and Passolunghi and Costa (2016)'s studies, an effect was observed on counting skills, which are part of the preschool program, but their training program included PL tasks, which are more related to counting than visuo-spatial CE (Noël, 2009).

Finally, we could question the effectiveness of WM training per se; our intervention had a restricted impact as improvement was observed in the trained modality only and the effects did not last in the long term. This is what seems to come out of most WM training studies: increased performances are usually observed in the trained or in very similar tasks only (Dunning et al., 2013; Sprenger et al., 2013; see Melby-Lervåg & Hulme, 2013 for a review) and there is little evidence that visuo-spatial WM improvement only might be sustained in the long term (Melby-Lervåg & Hulme, 2013). Hence, if WM cannot be significantly improved through training, it is difficult to assess its possible impact on numerical development. According to Shipstead, Redick, et al. (2012), the few far transfer effects observed in the WM training literature (fluid intelligence or attention) cannot be directly linked to WM improvement and Melby-Lervåg and Hulme (2013) conclude their meta-analysis by saying that there is no evidence of transfer effect to other cognitive abilities (verbal ability, word decoding and arithmetic). Then, in the specific case of Cogmed, two reviews (Hulme & Melby-Lervag, 2012; Shipstead, Hicks, et al., 2012) conclude that there is no convincing evidence that the training program leads to far-transfer effects. More importantly, the authors question the capacity of Cogmed training to enhance WM abilities. In addition, Shipstead, Hicks, et al. (2012) have pointed out that although complex span tasks are better measures of WM capacities, all the tasks of the training program are mostly simple span tasks (forward or backward span). To address this methodological issue, Shipstead, Hicks, et al. (2012) encourage researchers to adopt a stronger theory-driven attitude to develop adequate WM training program. For example, Gibson et al. (2012) developed a modified version of Cogmed based on Unsworth and Engle (2007)'s dual component model. In this model, WM is composed of two dissociable components: a primary memory which is responsible for the active maintenance of a limited amount of information and a secondary memory which is responsible for the retrieval of goal-relevant information from secondary memory once information has been lost from primary memory. Hence, Gibson et al. (2012)'s version of Cogmed targets not only the primary memory, as it is the case in the standard version of Cogmed, but also the secondary memory, by requiring the processing of a secondary task while maintaining information. Although the authors did not observe any gain in secondary memory capacities with their modified version of Cogmed, future research should follow their example and develop more theory-driven programs to investigate the possible efficiency of working memory training.

To conclude, the present study aimed to clarify the relation between WM and numerical abilities in preschoolers, using training as experimental design. Until now, the literature suggests that WM capacities are related to numerical skills, but only a few studies have examined this relation with the use of training studies and the results are unclear; in addition, results about the longevity of WM training effects are not consistent in the literature. Our data suggest that WM can be improved through intensive training but the effects are very limited: only the trained ability is enhanced and they do not last on the long term. Then, the present study shows that improved visuo-spatial WM capacities have a very small impact on mathematics; it seems to help children in their current learning related to the VSSP, but this effect is very weak and there is no transfer effect to arithmetic. Therefore, according to the present findings together with those of our previous study (Honoré & Noël, 2017), it seems more effective to directly train specific numerical processes to impact numerical development. Indeed, WM training leads to improvement in counting skills only if a numerical material is used (Kroesbergen et al., 2014) and Kyttälä et al. (2015) showed that training counting only, but not counting and WM abilities together, improves counting skills. In addition, numerous studies have shown that numerical training programs have a significant impact on numerical competences (Link, Moeller, Huber, Fischer, & Nuerk, 2013; Obersteiner, Reiss, & Ufer, 2013; Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009; Vilette, Mawart, & Rusinek, 2010; Wilson, Dehaene, Dubois, & Fayol, 2009). Training specific (numerical) rather than general (WM) processes should be favored to impact numerical development.

Nevertheless, it is possible that the absence of powerful WM training impact on WM abilities did not enable a real transfer effect to numerical skills. Therefore, and as most studies agree that numerical performance is especially related to CE abilities (Andersson, 2008; De Smedt et al., 2009; Holmes & Adams, 2006; Kroesbergen et al., 2009), future training studies should develop programs focusing on CE. Furthermore, to examine more precisely the impact of increased WM on numerical abilities, future research should focus on school-aged children who might benefit more than younger children from WM training as they can develop strategies and they could directly transfer to their concurrent learning. Another alternative would be to implement an arithmetical session at the end of the WM training period, which would allow the researcher to control concurrent numerical learning and to compare children with and without enhanced WM abilities dealing with this new learning.

Notes

i) All participants were included in the analyses and control analyses in which the Spanish participant was excluded did not change the global profile of the results.

ii) This study being part of a larger project examining the impact of training on numerical development, we deliberately used the same methodological design as in a previous work (Honoré & Noël, 2017), which leads to overlaps in the textual description.

iii) In a related paper (Honoré & Noël, 2017) a small number of statistical values from the work described here were reported by mistake in an initial published version. These have been corrected in an updated version.

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Competing Interests

The authors have declared that no competing interests exist.

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