Training of Visual-Spatial Working Memory in Preschool Children

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ABSTRACT

Working memory, the ability to store and manipulate information is of great importance for scholastic achievement in children. In this study, we report four studies in which preschoolers were trained on a visual-spatial working memory span task, namely the Corsi Block Task. Across all four studies, we found significant training effects for the intervention groups compared to active control groups. Confirming recent research, no transfer effects to other working memory tasks were found. Most importantly, our training effects were mainly brought about by children performing below the median in the pretest and those showing median performance, thereby closing the gap to children performing above the median (compensation effect). We consider this finding of great interest to ensure comparable starting conditions when entering school with a relatively short intervention.

KEYWORDS

working memory, preschoolers, training, compensation

INTRODUCTION

Working memory (WM) is assumed to ensure the availability of information formerly learnt as well as the integration of this information to resolve problems encountered during cognitive performance. Whereas most researchers agree with the above definition of WM as an important cognitive device for higher order cognition, many different models have been proposed to exactly specify the underlying components of WM and their interactions (see, e.g., Baddeley, 1986; Gray et al., 2017; Logie, 2016; Miyake & Shah, 1999; Oberauer, 2009). Most models so far assume material-specific storage components (i.e., verbal and visual-spatial) as well as coordinating attentional functions (i.e., shifting from one object to another or updating of WM content) to achieve intended goals. Regardless of the underlying model and its precise nature, WM measured through different tasks has been shown to be crucial for scholastic achievements, and its failures are diagnostic for academic drop-outs (Alloway & Alloway, 2010; Alloway, Gathercole, Willis, & Adams, 2004; Fitzpatrick & Pagani, 2012; St Clair-Thompson & Gathercole, 2006). In addition, several (disturbed) WM processes are proposed to be fundamental to learning difficulties like dyscalculia and reading disabilities (Landerl, Fussenegger, Moll, & Willburger, 2009; Passolunghi & Mammarella, 2012; Schuchardt, Mähler, & Hasselhorn, 2008). Thus, WM processes are at the core of scholastic achievement starting at kindergarten (see Fitzpatrick & Pagani, 2012, amongst others).

Amongst classical precursor skills for reading or mathematic abilities, like phonological awareness or quantity-number competencies, WM seems to be important not only as precursor itself, but as an ability that moderates the functioning of other precursors (Krajewski & Schneider, 2009; Passolunghi & Lanfranchi, 2012; Preßler, Krajewski, & Hasselhorn, 2013).

Since WM is not only fundamental to the acquisition of academic abilities but also to learning difficulties, the training of WM seems an optimal pathway for overcoming constraints in academic achievement. Albeit the training of (pre-)school children's WM showed substantial improvement within the trained WM tasks over a short period of time, it is still debated to what extant training can be generalized to other

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processes and whether observed training effects are maintained over longer periods of time (see Diamond & Lee, 2011; Melby-Lervåg & Hulme, 2013; Sala & Gobet, 2017; Schwaighofer, Fischer, & Bühner, 2015, for recent reviews and meta-analyses). Different types of effects after training can be demonstrated depending on the duration of the trainings, the type, as well as the variety of tasks employed and the level of the to-be trained processes (see Sala & Gobet, 2017; Schwaighofer et al., 2015). However, most training studies focus on three different outcomes. First of all, there are practice effects on the tasks used in the training program (task-training effects). Second, if training is not only task-specific but is thought to tackle more general processes (i.e., acquisition of general skills to react to certain task affordances), training positive outcomes (i.e., improvements) on the nontrained tasks that also tap into related working memory processes (*near-transfer tasks*) should be observed. Third, it has been proposed that inasmuch as training affects general processes, such as cognitive speed or problem solving capabilities, there should also be outcomes of training observable on unrelated measures, such as IQ (i.e., *far-transfer,* see Sala & Gobet, 2017).

In their meta-analysis, Melby-Lervåg and Hulme (2013) conclude that WM training studies only show a short-term effect of medium size—a finding further corroborated by more recent meta-analyses (Sala & Gobet, 2017; Schwaighofer et al., 2015). Furthermore, the near-transfer to related but not trained tasks was low (see also Rode, Robson, Purviance, Geary, & Mayr, 2014), as was far-transfer (Sala & Gobet, 2017; Schwaighofer et al., 2015). Thus, we followed a suggestion by Schwaighofer et al. (2015) and opted against a training involving several tasks. We constrained ourselves to one aspect of WM only, being more interested in training gains for visual-spatial WM only by using just one task, presuming that those trainings impact basic cognitive functions (Klauer, 2001; Schwaighofer et al., 2015).

Additionally, we decided to train children of age groups that received little attention, namely preschoolers. Interestingly, in the meta-analysis by Melby-Lervåg and Hulme (2013), data suggested that WM training is more effective in younger children than in older children or in adults. The beneficial effect of training for young children is also supported by other reviews as well (Wass, Scerif, & Johnson, 2012). Wass et al. (2012) interpret the larger training impacts in young children being due to a lack of differentiation of cognitive functions within younger children. Yet only few studies have been conducted on WM training in children below school age. In a recent study, Thorell, Lindqvist, Bergman Nutley, Bohlin, and Klingberg (2009) investigated the effects of two specific training programs focusing on either visual-spatial WM or inhibitory control in a sample of preschool children. They found that WM training was effective even among their sample of preschool children on the trained as well as on nontrained WM tasks within both the spatial and the verbal domains. Furthermore, a significant transfer effect on laboratory measures of attention could be found.

Given these promising results and the impact of WM functioning on cognitive abilities in children and their academic achievement, we designed a short training of visual-spatial WM for preschoolers which would enter formal schooling at the end of summer. We were interested not only in overall training effects, but also in whether our training would show compensatory effects over and above improving performance in the trained task (Klauer, 2001) as well as in near-transfer tasks. The choice for processes underlying visual-spatial WM was based on recent findings highlighting the role of visual-spatial WM processes in solving arithmetic problems and number writing before school entry and within the first grade (Grube & Seitz-Stein, 2012; Rasmussen & Bisanz, 2005; Simmons, Willis, & Adams, 2012). Additionally, researchers also suggest that preschool children tend to rely on visual-spatial WM more than on phonological WM (Hitch, Halliday, Schaafstal, & Schraagen, 1988). Being able to train processes in visual-spatial memory might have beneficial effects for early mathematical capabilities becoming important after school entry (Landerl et al., 2009).

METHOD

In four studies, we tested for the convertibility of visual-spatial WM using a small, task-based training. In addition, all four studies comprised tests measuring verbal WM, using a mono-syllabic word span task, and attentional functions, using an object span task (Study 1) or a color span backwards task (Study 2, 3, and 4) from the Arbeitsgedächtnistestbatterie (AGTB 5-12 battery, Engl. "Working Memory Test Battery"; Hasselhorn et al., 2012). Next, a second measure for visual-spatial WM, the Matrix Task from the AGTB, was used in all four studies to test for near-transfer effects. Even though one study differed in measures of the executive functions assessed, the remaining measures of all studies were the same. Additionally, the most important dependent variable in all four studies was the same, namely the Corsi Block Task in its computerized version in the AGTB. Furthermore, the training in all four studies was given using standardized instructions (see below). Next, all samples were recruited in Upper Bavaria (to keep teaching curricula constant) and experimenters received advanced training on all measures employed.

Participants

In Study 1, 20 children (9 girls, M_{age} = 5.2 years; SD = 0.5 years) took part. In Study 2, 31 children (15 girls, M_{age} = 5.6 years; SD = 0.4 years) participated. In Study 3, 20 children took part (10 girls, M_{age} = 6 years; SD = 0.3 years), and in Study 4, also 20 children (10 girls, M_{age} = 5.11 years; SD = 0.3 years) participated. All children were sampled from kindergartens in Upper Bavaria, and informed consent of the parents was collected.

TASK AND MATERIALS FOR PRE- AND POSTTEST ASSESSMENT

In all four studies, pre- and posttest assessments were performed using the AGTB 5-12 (Hasselhorn et al., 2012)—that is, a computerized WM test battery in which children were asked to either respond verbally (with their responses being coded by the experimenter) or using a touch screen to indicate their responses. The computer used for stimulus presentation was a Dell notebook (Latitude D530), the external touchscreen employed measured 15 in. All stimuli were presented centrally with good luminance and clear color. No direct stimulus repetitions were allowed, and children reported no problems with hearing the acoustic stimulation (i.e., instructions and stimuli). For the selection of stimulus material, it was ensured that children knew all objects named during the tasks and all words being used. Furthermore, it was ascertained that children had good color vision and naming abilities. Overall, the subtests used from the AGTB had acceptable reliabilities given the young age of the children (see Appendix), and were comparable to other measures (i.e., Working Memory Test Battery for Children [WMTB-C]; Pickering & Gathercole, 2001).

In each of the tasks, an adaptive algorithm was used to measure performance. In each task, children performed five blocks of two trials with the same sequence[1] length. The two trials in the first block were used for calibration. As soon as children solved one of these trials correctly, the sequence length was increased by one item for the next trial. After the first block, by entering the test blocks, participants had to solve both of the next two trials correctly to increase sequence length by one item. If they solved only one sequence correctly, the sequence length remained the same for the next block. In case of two incorrectly solved trials, the next block started with a sequence decreased by one item. In the testing session, to indicate the presented sequences, children performed the tests using the touch screen and vocal responses recorded by the experimenter.

From this WM test battery, the following tests were administered to children in pre- and posttests that constituted two separate sessions and tested children at a laptop with an external touchscreen to record children's responses.

For visual-spatial WM, we used the Corsi Block Task as well as the Matrix Task (near-transfer). In the Corsi Block Task, children encountered a 2D version of a Corsi board with nine boxes displayed on the computer screen. On this board, they had to repeat a sequence of variable length by touching the screen, starting from the length of two up to maximally nine (possible) items. The sequence was indicated by a smiley that briefly (950 ms) highlighted one of the boxes. After an intertrial interval of 50 ms, the smiley highlighted the next block. The task comprised eight test trials after a practice and a calibration phase (start with two items). Starting of one series was initiated by the experimenter. There were no stopping rules. Longest series achieved was used for analysis.

In the Matrix Task, children encountered a four by four Matrix in which some fields were filled (per filled field presentation time was prolonged by 1.2 s). The children's task was to reproduce the pattern encountered by touching the formerly filled fields. The Matrix sequence again started with two filled fields, and participants were given two trials per sequence to reproduce the observed pattern correctly. The task comprised eight test trials after a practice and a calibration phase (again, start with two items). In case children successfully completed the series, the next series contained one more block to touch. The next series was initiated by the experimenter. There were no stopping rules. Longest series achieved was used for analysis. The Matrix Task was analysed to assess near-transfer effects within the same WM domain.

To test verbal WM, children were given the Word Span Task from the AGTB that comprised nine monosyllabic words. Again, testing started with 2 monosyllabic words which were presented acoustically to the children (spacing of 1 s) and was increased by one word after correct reproduction of both sequences. Children worked through eight test trials after a practice and calibration phase that started with two items to be recalled verbally. There was no stopping rule, and the series were initiated by the experimenter. Longest series achieved was used for analysis. The Word Span Task was used to assess far-transfer, as it employs a different material-specific domain.

To assess the executive—that is, attentional functions, two different tasks from the AGTB were used across the four studies. In Study 1, children were given an Object Span Task in which they had to remember the occurring objects and judge them as edible or not. Presentation time was 1 s per object. Starting with two objects, correct reproduction of two sequences led to the increase of sequence length by one more object. However, the Object Span Task seemed to be too difficult for preschool children, as indicated by floor effects (see Table 2), and was therefore exchanged for the Color Span Backwards Task from Study 2 onwards. Please note that also in this exchanged task measuring executive functions of WM, children performed quite badly given their young age and the complexity of the task (i.e., reversing the order of colors given to them). The Color Span Backwards Task started with two colors in a row which were presented for 2 s. The children's task was to correctly reproduce the presented sequence of colors in reversed order. Again, after correct reproduction of two sequences of similar length, color span was increased by one color and presentation time adjusted by 1 s. The last correctly reproduced series was taken as a performance indicator for the executive functions. There was no stopping rule, and the series were initiated by the experimenter. Again, the Object and Color Span Tasks were used to assess far-transfer effects.

For transfer tests, we used the very same tasks as in the pretest. Near-transfer tasks were defined as tapping into the same WM domain (i.e., visual-spatial) as the task trained, whereas far-transfer tasks were tasks relying on verbal WM (i.e., monosyllabic Word Span Task) or attentional functions (i.e., Color Span Backwards). If our training reaches over and above the trained task, the processes used to solve the Corsi Block Task should also benefit the other WM tasks assessed in this study.

As overall task framing, all children were introduced by a cover story of a journey into the land of dwarfs in which dwarfs play catch games with another dwarf, a fairy, or a goblin. To ensure continuous participation, children got a sticker they could stick to a sheet of paper for each session they participated in.

TASK AND MATERIALS FOR THE ACTIVE CONTROL GROUPS

In the active control groups, children were read small stories about a dwarf, a fairy, and a goblin and were given sheets of papers to draw sceneries of the stories told or asked to color preprinted fairy tale pictures. The procedure of the active control group was chosen based on consideration that the children interacted with each other during the time without training and should not become aware of too much differences between the two groups which we ensured by introducing comparable cover stories with similar protagonists. Next, we also wanted to make sure that our training procedure trains cognitive processes over and above those commonly employed in simple daily activities, such as drawing or coloring, for which it has been speculated that these processes also rely on visual-spatial WM (Bradimonte, Hitch, & Bishop, 1992). Therefore, any training effects observed should be attributable to the specific Corsi Block Task training and the processes involved in this task, and not to enhanced engagement in common daily activities in the kindergarten, such as drawing.

Task and Materials for the Training Groups

For the training groups, children were given Corsi Block Task boards with nine blocks on solid wooden boards, on which some blocks were removed for six block training sessions or added in the 12 block training sessions (see below). The task was the physical reproduction of sequences shown by the experimenter. The green Corsi boards measured 275 mm × 275 mm, were about 1 cm thick. and had either six red, nine blue, or 12 yellow wooden blocks that measured 25 mm mounted upon them (see Figure 1). Training took place once a day in the morning at the kindergarten for nine or 12 consecutive days, excluding weekends or days the child was not at kindergarten because of illness.

Procedure

Sorting to training and control groups was random. In the first session, children were tested alone with the above-mentioned tasks from our WM test battery (AGTB) with an external touchscreen. Afterwards, they either trained the Corsi Block Task on the wooden boards in interactive company of the experimenter for nine or 12 sessions of 15 min, or they were told a story and allowed to draw or color a picture related to the overall topic of "Journey to the Land of Dwarfs". Only in Study 4, training comprised 12 sessions, as did the activities of the control group. Within the training groups, children were given the figure of a dwarf that loves to play a catch game together with a dwarf (six blocks field), a fairy (nine blocks field), or a goblin (12-block field) to reproduce the sequences shown by the experimenter on the Corsi board placed in front of them. The experimenter used the other figure (a dwarf in the beginning, later on a fairy or a goblin) to draw a sequence the child had to reproduce with its figure. To highlight the different Corsi boards the children worked on and to prevent boredom during the training, the figures of the stories and the games these figures liked to play changed. Children were given 14 sequences during one session and allowed to create some two sequences at the end, in which the experimenter had to reproduce their sequence. In case the children correctly reproduced two sequences of the same length, one item was added to the sequence. The nine- and 12-block fields were introduced after three training sessions (thus, in training Sessions 4 and 7). For Study 4, training with each of three Corsi boards comprised four sessions, and new boards were introduced in Sessions 5 and 9. In each session, the starting sequence was one block less than the last correctly reproduced sequence length. After the end of the training sessions, children were assessed solely in the posttest using computerized tasks drawn from the AGTB (i.e., Word Span, Color Span Backwards, Matrix Task, and Corsi Block Task), given a certificate, and thanked for their participation.

RESULTS

Data were analyzed using SPSS (version 20). We performed a mixed 2 × 2 analysis of variance (ANOVA) in all tasks to assess differences between groups in pre- and posttests and to test for training as well as transfer effects. The ANOVA comprised Time (pre- vs. posttest) and Group (experimental vs. control) as factors.

To assess baseline differences across tasks, we used independent group *t*-tests for pretest performance. Uncorrected degrees of freedom are reported, yet corrections were applied when necessary (i.e., in case of unequal variances). Scores for pre- and posttests in the Corsi Block Task for all four studies can be found in Table 1. Scores for pre- and posttests for all other WM measures can be found in Table 2. For reporting, we will start with the training effects (i.e., the 2 × 2 ANOVA for the Corsi Block Task) and report the transfer ANOVAs (the Matrix Task, the Word Span Task, and either the Object Span Task in Study 1 or the Color Span Backwards Task in Studies 2 to 4) separately.

Performance Over Training Sessions

As regards performance over training sessions, all four studies showed a remarkably similar pattern (see Figure 2). Within each study, large performance improvements were seen especially after the first two sessions. Afterwards, performance improvements got smaller. Yet, as expected, performance dropped directly after the introduction of a new board (i.e., after Sessions 3 and 6, but see Study 1, or Sessions 4 and 8 for Study 4) but recovered during the next sessions. However, performance drops were more remarkable in the seventh sessions (or

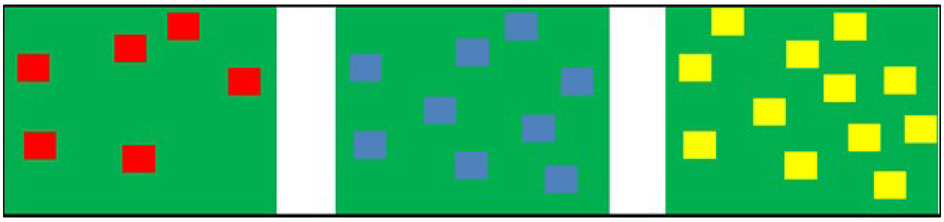

FIGURE 1.
Layout of Corsi boards for training.

TABLE 1.

Mean Values of Pretest and Posttest Performance for All Four Studies in the Corsi Block Task for Training and Control Group

Study	Group	Pretest	Posttest	Training Gain
1	Training	3.45 (1.01)	4.25 (0.54)	.80
	Control	3.70 (0.92)	3.60 (0.74)	−.10
2	Training	3.38 (0.62)	3.94 (0.57)	.56
	Control	3.33 (0.82)	3.53 (0.74)	.20
3	Training	3.10 (0.74)	3.90 (0.32)	.80
	Control	3.60 (0.52)	3.50 (0.71)	−.10
4	Training	3.60 (0.52)	4.00 (0.47)	.40
	Control	3.80 (1.14)	3.90 (0.88)	.10

Note. Standard deviation (*SD*) in parentheses.

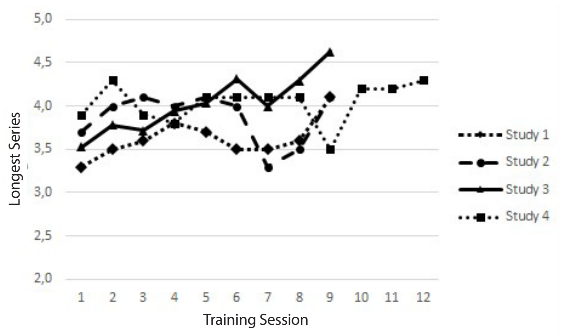

FIGURE 2.

Training performance for all four studies. For all studies, we depicted the mean longest correct series achieved within a session. For Study 3, the mean longest two correct series achieved were depicted because of an unresolvable coding error.

TABLE 2.

Mean Values of Pretest and Posttest Performance for All Four Studies in All Tasks Assessed Except the Corsi Block Task for Training and Control Group

Study	Task	Group	Pretest	Posttest
1	Word Span	Training	3.1 (1.1)	3.6 (.70)
		Control	2.8 (.42)	3.1 (.74)
	Matrix	Training	3.2 (.67)	3.9 (.74)
		Control	3.4 (1.0)	3.9 (1.2)
	Object Span	Training	2.4 (.52)	2.4 (.69)
		Control	2.4 (.53)	2.2 (1.1)
2	Word Span	Training	3.6 (.63)	3.88 (0.62)
		Control	3.5 (.52)	3.40 (0.63)
	Matrix	Training	3.0 (.63)	3.38 (0.72)
		Control	3.1 (.80)	3.40 (0.83)
	Color Span Backwards	Training	2.19 (.54)	2.19 (0.40)
		Control	2.00 (.53)	2.20 (0.86)
3	Word Span	Training	3.90 (0.32)	4.00 (0.47)
		Control	3.80 (0.42)	3.80 (0.42)
	Matrix	Training	3.20 (0.63)	3.20 (0.63)
		Control	3.10 (0.57)	3.30 (0.95)
	Color Span Backwards	Training	2.40 (0.52)	2.50 (0.53)
		Control	2.40 (0.52)	2.30 (0.67)
4	Word Span	Training	3.60 (0.70)	3.80 (0.42)
		Control	3.50 (0.53)	4.00 (0.47)
	Matrix	Training	3.40 (0.52)	3.10 (0.74)
		Control	3.70 (0.95)	4.10 (1.20)
	Color Span Backwards	Training	2.30 (0.48)	2.10 (0.32)
		Control	2.40 (0.52)	2.50 (0.53)

Note. Standard deviation (*SD*) in parentheses.

ninth in Study 4), namely after the introduction of the board with 12 blocks. We attribute this sharper drop to nonlinear effects of complexity of the board and the young age of our participants. However, also after this drop, performance recovered quickly until the end of training. Please note that this rather nonlinear pattern across training sessions in combination with the fixed increase in complexity during the training makes it relatively difficult to quantify training gains.

Overall, it seems notable that across studies, gains in training sessions were small. This could be due to our algorithm that required two correctly performed sequences before moving on to a longer sequence, which might have been hard to achieve considering the young age of our participants.

Results Within the Specific Studies

STUDY 1.

Training task (*Corsi Block Task*). In our first study, we observed significant differences in posttest performance for the Corsi Block Task between the two groups, whereas no difference could be detected for pretest performance, $t_{corsi}(18) = -0.58$, $p = .57$. The significantly different gain in performance of the training task was statistically confirmed by a significant time point by group interaction in the ANOVA, $F(1, 18) = 6.63$, $p = .02$, $\eta_p^2 = .27$. Measurement of differences in performance in the Corsi Block Task between pre- and posttest in both groups just missed significance, $F(1, 18) = 4.01$, $p = .06$, $\eta_p^2 = .18$, but could be confirmed by follow-up *t*-tests. Overall, the training group achieved an average sequence of 4.25 items as longest correctly recalled series, whereas the control group only managed to correctly reproduce an average series of 3.6 items, $t(18) = 2.25$, $p = .04$.

Transfer tasks. For near-transfer (Matrix Task), there was neither a difference in pretest nor in posttest performance between the groups, $t_{matrix}(18) = -0.61$, $p = .55$, versus $t_{matrix}(18) = 0.00$, $p = 1.00$, for the longest correctly reproduced series in pre- and posttest, respectively. Overall, children showed a significant improvement in near-transfer task performance, $F(1, 18) = 18.80$, $p < .01$, $\eta_p^2 = .51$, but did not do so differentially for training versus control group, $F(1, 18) = 0.16$, $p = .36$, $\eta_p^2 = .05$. For the two far-transfer tasks, we again found no significant difference in pretest measures in the Word Span Task, $t_{\text{word span}}(18) = 1.56$, $p = .14$, as well as in the Object Span Task in which the data of one child were lost, $t_{\text{object span}}(17) = .43$, $p = .68$. For posttest performance, a significant performance gain compared to pretest performance was observed for the Word Span Task, $F(1, 18) = 8.73$, $p = .008$, $\eta_p^2 = .33$, but this performance gain occurred in both groups, $F(1, 18) = 0.55$, $p = .47$, $\eta_p^2 = .03$, for the interaction. For the Object Span Task, no difference emerged for either training group or time of testing, $F(1, 18) = 0.42$, $p = .53$, $\eta_p^2 = .02$, for both time main effect and the interaction (see Table 2).

STUDY 2.

Training task. Like in Study 1, pretest performance did not differ significantly between groups, $t_{\text{corsi}}(29) = 0.16$, $p = .88$. In the ANOVA of the posttest performance gains, Corsi Block Task performance improved significantly from pretest ($M = 3.35$) to posttest ($M = 3.74$), $F(1, 29) = 4.96$, $p = .03$, $\eta_p^2 = .15$, but did so for both groups, $F(1, 29) = 1.12$, $p = .30$, $\eta_p^2 = .04$, for the interaction.

Transfer tasks. Like in Study 1, no difference was observed in the near-transfer task at pretest, $t_{\text{matrix}}(29) = -0.26$, $p = .80$. Overall, children showed a significant improvement in near-transfer task performance, $F(1, 29) = 7.47$, $p = .01$, $\eta_p^2 = .21$, but again, not differentially for training versus control group, $F(1, 29) = 0.26$, $p = .87$, $\eta_p^2 = .001$.

In the two far-transfer tasks, we observed, again, no difference at pretest between the groups, $t_{\text{word span}}(29) = .46$, $p = .65$, and $t_{\text{color span backwards}}(29) = .97$, $p = .34$, respectively. In posttest performance, we found neither a significant performance improvement for both groups in both tasks, Word Span as well as in Color Span Tasks, $F(1, 29) = 1.31$, $p = .26$, $\eta_p^2 = .04$, and $F(1, 29) = 0.72$, $p = .40$, $\eta_p^2 = .02$, respectively, nor any differential influence of group, $F(1, 29) = 3.19$, $p = .09$, $\eta_p^2 = .10$, for the interaction in the Word Span Task, and $F(1, 29) = 0.72$, $p = .40$, $\eta_p^2 = .02$, for the interaction in the Color Span Backwards Task (see Table 2).

STUDY 3.

Training task. No difference in pretest performance was detected between the two groups, $t_{\text{corsi}}(18) = 1.76$, $p = .10$. However, the training group showed significantly larger gains in posttest performance compared to the control group as indicated by the significant interaction, $F(1, 18) = 6.94$, $p = .02$, $\eta_p^2 = .278$. However, like in Study 1, the children in the control group showed a small decline in their performance on the posttest Corsi Block Task (see Table 1). Like in Study 1, measurement of differences in Corsi Block Task performance for both groups just missed significance, $F(1, 18) = 4.20$, $p = .06$, $\eta_p^2 = .19$.

Transfer tasks. In the near-transfer task, training and control groups did not differ at pretest, $t_{\text{matrix}}(18) = 0.37$, $p = .71$. In posttest performance, there was neither a significant overall performance gain, $F(1, 18) = 0.44$, $p = .84$, $\eta_p^2 = .002$, nor a differential gain in for the experimental group, $F(1, 18) = 2.15$, $p = .16$, $\eta_p^2 = .11$. For the two far-transfer tasks, no initial performance differences were detected, *t*word span(18) = 0.60, $p = .56$, and $t_{\text{color span backwards}}(18) = 0.00$, $p = 1.00$, respectively. For posttest performance and differential transfer effects between the groups, the ANOVAs showed a significant performance gain in the word span task, $F(1, 18) = 7.23$, $p = .02$, $\eta_p^2 = .29$, but this gain occurred uniformly across training and control groups, $F(1, 18) = 1.33$, $p = .26$, $\eta_p^2 = .07$, for the interaction, see Table 2. In the Color Span Backwards Task, no performance gain for posttest performance was observed, $F(1, 18) = 0.20$, $p = .66$, $\eta_p^2 = .01$. No group, training, or control, was affected differentially, $F(1, 18) = 1.80$, $p = .20$, $\eta_p^2 = .09$, see Table 2.

STUDY 4.

Training task. No difference in pretest performance was detected between the two groups, $t_{\text{corsi}}(18) = -0.51$, $p = .62$. In the ANOVA, we found neither a significant improvement in the Corsi Block Task, $F(1, 18) = 3.08$, $p = .10$, $\eta_p^2 = .15$, for all participants from pre- to posttest, nor a selective improvement for the training group only, $F(1, 18) = 1.10$, $p = .31$, $\eta_p^2 = .06$, for the interaction.

Transfer tasks. In the near transfer task, we observed no significant difference between groups at pretest, $t_{\text{matrix}}(18) = -0.88$, $p = .39$. Performance in this task remained nearly stable also at posttest, $F(1, 18) = 0.23$, $p = .64$, $\eta_p^2 = .01$, for the main effect of time and was also not different between groups, $F(1, 18) = 0.23$, $p = .64$, $\eta_p^2 = .01$, see Table 2. In the other two far-transfer tasks, we observed no significant differences between training and control group at pretest, $t_{\text{word span}}(18) = 0.36$, $p = .77$, and $t_{\text{color span backwards}}(18) = -0.45$, $p = .66$, respectively. In the ANOVAs, assessing posttests improvements, we found no improvements, $F(1, 18) = 0.31$, $p = .58$, $\eta_p^2 = .02$, for the Word Span Task, as well as $F(1, 18) = 0.00$, $p = 1.00$, $\eta_p^2 = .00$, for the Color Span Backwards Task. No differential influences emerged for either task, $F(1, 18) = 0.31$, $p = .58$, $\eta_p^2 = .02$, for the Word Span Task, and $F(1, 18) = 0.62$, $p = .44$, $\eta_p^2 = .03$, for the Color Span Backwards Task.

Across-study analysis. To assess whether the rather unreliable effect of training was due to our low number of children in the training group (i.e., 10 to 16 children did the training in each study), we decided to combine all studies given that the training administered was highly standardized and therefore comparable across studies. If the observed training effects are indeed driven not only by performance gains in Study 1 and 3 but also by children in the control groups dropping in their performance, no overall training effects should be observed. In the overall, mixed effects 2 × 2 × 4 ANOVA, we compared pre- and posttest performance (i.e., time) in the computerized version of the Corsi Block Task for all participants (i.e., group with two levels, control and training) and entered Study (1 to 4) as a between-subjects factor to control for differences across studies that might have existed. In this overall ANOVA, we confirmed the significant training gain for the training group over the control group by the time point by group interaction, $F(1, 83) = 12.52$, $p = .001$, $\eta_p^2 = .13$, which, most importantly, was not moderated by study, $F(3, 83) < 1.00$, $p = .45$, $\eta_p^2 = .03$, for the three-way interaction. Thus, when combining the studies to increase power, this mixed ANOVA confirmed the overall effectiveness of the training intervention. Children participating in the training intervention outperformed the children in the active control group in the posttest assessment in the Corsi Block Task of the AGTB. However, next to the finding that training helps children, given the perspective

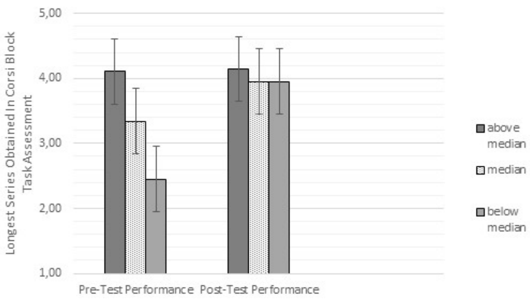

FIGURE 3.

Training gains by group based on median splits. Error bars depict *SDs* of the mean. Note: Corsi Block Span started with 2 blocks and was mastered by all children.

of the trained children to start formal schooling quite soon, we were interested in differential training effects—that is, the compensatory enhancement of otherwise children-at-risk for achievement problems in school. Therefore, we employed a median split procedure for each study based on the pretest score achieved. Children were split in three groups, namely, those children performing below the median of their respective study (n = 10), those showing median performance (n = 22), and those above the respective median of their study (n = 14) and could establish differential training gains for each group as indicated by the significant interaction, $F(2, 35) = 27.94$, $p < .01$, $\eta_p^2 = .62$. Children performing below the median in the respective study showed a significantly larger training gain (M = 1.50) compared to children performing above the median in the respective study (M = 0.04), $t(22) = 6.45$, $p < .01$, and also larger training grains compared to the group achieving the median at pretest, $t(30) = 3.84$, $p = .001$, see Figure 3. Furthermore, children showing medium performance at pretest had larger training gains (M = 0.61) than those performing above the median in their respective study, $t(30) = 2.71$, $p = .01$. Most importantly, posttest performance was not significantly different between the groups, $F(2, 44) = 0.67$, $p = .57$.

This finding of a differential training effect was further corroborated by analysis of correlation coefficients for pre- and posttest performances in the Corsi Block Task. We reasoned that when our training does indeed have differential effects, the correlation between pre- and postassessment of this task should break down in the training group but remain more or less stable in the control group. This was precisely what we found, correlation between pre- and posttest for the Corsi Block Task was $r = .49$, $p = .001$, for the control group; a much smaller, nonsignificant correlation was observed in the training group, $r = .22$, $p = .14$. We attribute this lack of a significant correlation between pre- and posttest in the Corsi Block Task to our differential training effects that benefitted especially those children that performed worse in the pretest and also those children performing at medium level. However, given the rather limited range of scores achieved by the children (between two and five items mainly out of maximally nine items), we cannot properly rule out ceiling effects (due to neuronal developmental achievement) for the group above the median (see also the Discussion section). Therefore, further research on this topic seems warranted (see Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005, for a related discussion).

DISCUSSION

The main aim of the present study was to assess the gains arising from a short, task-based intervention on cognitive functions important for scholastic achievement. Across four studies, we were able to show the effectiveness of short visual-spatial WM training for preschoolers. Next to general task-learning effects, we could establish compensatory effects that account for the main portion of the observed training effect.

Trainings of basic cognitive functions, such as WM, received a lot of attention during the last decade (see Klingberg, 2010, for an overview, Melby-Lervåg & Hulme, 2013; Sala & Gobet, 2017; Schwaighofer et al., 2015, for recent reviews and meta-analyses). Given the importance of WM functioning for scholastic achievement in children, this is not astonishing. Therefore, having designed a short intervention for preschoolers that benefits those children performing poorly at pretest is desirable, especially given the prospect of formal schooling ahead. In the following, we want to discuss our results with respect to recent critiques being brought forward about cognitive training in general and the potential weaknesses of our study.

Given the many different recipes of how to design a working WM training (see Schwaighofer et al., 2015; Shipstead, Redick, & Engle, 2012), we would like to address three points, first the number of training sessions necessary to observe training effects, the duration of each session, and finally the variety of tasks assessed in the training. Klingberg (2010; see also Shipstead et al., 2012) argue for long training schedules comprising approximately 20 sessions. Yet, our training effects were observed after 9 to 12 training sessions, which supports the significant on-task learning effects following a power law reported in other studies (Rode et al., 2014). However, one could argue that our training sessions were beneficial for children performing poorly in the pretest, somewhat beneficial for children starting with median performance, yet not sufficient for children being above median performance in the pretest. For those children, there is the possibility that longer training would have yielded larger training gains (but see Henry, Messer, & Nash, 2014; Rode et al., 2014, that report no differential effects of training based on pretest scores within the training group for trainings comprising more than 17 sessions). However, it is also feasible that not yet accomplished neural maturation processes did not permit stronger training effects (see, e.g., Rueda et al., 2005, for a discussion of the contribution of training and maturation), especially for the children performing above the median for which only a very small training effect was observed (i.e., ceiling performance).

Yet, another suggestion to make WM training effective (Klingberg, 2010; Shipstead et al., 2012) is tied to the length of training session. Again, other studies (Henry et al., 2014; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; Rode et al., 2014) next to our own used sessions between 10 and 30 min long and still found significant training effects. Henry et al. (2014) discuss the face-to-face interaction as a potentially important mediator in the training session that is not present in case of computerized training based on CogMed[2] and other training software but might be especially helpful and supporting in case of preschool children. In their study, Henry et al. (2014) reported enhanced motivation of the children that enjoyed the interaction with the trainer during the session, a feature given in our training study as well. In our study, both groups, training and control, experienced interactions with the experimenter and, unfortunately, we did not ask for ratings of enjoyability of both of the interventions, the training as well as the control group activity. We therefore think that the quality of the interaction in training design for preschoolers for both training and control groups clearly warrants further investigation (see also Sala & Gobet, 2017; Schwaighofer et al., 2015, for related suggestions).

As regards the request for a variety of tasks to be trained (Shipstead et al., 2012), we would like to argue that given the age of our samples, a reduction of the number of tasks might actually be better to keep the children at training and not to overcharge them with different tests. Furthermore, our task-specific training might have actually fostered the development of strategies as to how to solve the task (Henry et al., 2014; Schwaighofer et al., 2015; Siegler & Jenkins, 2014). In consequence, given the development of strategies as to how to solve the task in the enriched training situation, children were able to transfer those strategies to less enriched testing situation, namely, the computerized Corsi Block Task on the laptop without problems, thereby maintaining their level of achievement from the training (Brown & Kane, 1988).

Please note that our study did not include active control groups that performed the same task at a lower level of complexity (i.e., a Corsi Block Task with two blocks). However, we speculate that given that our control group children also engaged in visual-spatial processing tasks (i.e., looking at stories and coloring pictures), it might have been that they also received a training of visual-spatial WM, the effects of which have yet to be examined. The exact contributions of WM in drawing have to be specified (see, e.g., Bradimonte et al., 1992, for visual-spatial memory involvement in imagery or Toomela, 2002, for verbal memory that provide both likely candidate mechanisms), but we think they provide an interesting alternative explanation for the failure to find effects of our training in all studies.

Unfortunately, but in line with other research (Melby-Lervåg & Hulme, 2013; Rode et al., 2014), we found no near-transfer effects to tasks measuring other WM components. However, it should be noted that the existence of (even near) transfer effects is undecided at best (Sala & Gobet, 2017; Schwaighofer et al., 2015). Some studies (Foy & Mann, 2014; Henry et al., 2014) report transfer to other WM tests (at least on spatial WM) or even more distant tasks (Chein & Morrison, 2010). We speculate that one reason for the failure to observe near-transfer in our study might be that our training sessions, face-to-face interactions with toys and a cover story, and the testing situation in front of a computer were highly distinct, which might have abolished transfer effects to other tasks, even to the Matrix Task that also measured visual-spatial WM. However, it has been found that the correlation among the Corsi Block Task and the Matrix Task, although these tasks are commonly used to assess visual-spatial WM, are of modest size at best (Gathercole, Pickering, Ambridge, & Wearing, 2004; Roebers & Zoelch, 2005; Schmid, Zoelch, & Roebers, 2008) in accordance with our data set.

In addition, it might be that the different, material-specific subdomains in WM are not present at this young age of our training group (but see Michalczyk, Zoelch, & Hasselhorn, 2012; Roebers & Zoelch, 2005). In the study by Roebers and Zoelch (2005), the presence of subsystems in children comparable to our age groups was observed (but see Alloway et al., 2004; Schmid et al., 2008, for diverging results that do not align with the idea of material-specific subdomains). To conclude, even though there is some evidence for different components of WM even in our young age group, coordinating functions that are commonly attributed to the executive functions seem to be still underdeveloped (Luciana & Nelson, 1998), and processes engaged in task performance do not seem to generalize across task demands.

However, although we obtained an overall training effect, task-specific training might be a valid alternative explanation for our results. This explanation receives some support from the fact that we did not even observe transfer to another task commonly used to measure visual-spatial WM when assessed, namely, the Matrix Task that was assessed in pre- and posttests in all four studies (but see cited correlational studies). Therefore, we cannot rule out task-specific practice and therefore an increase in task familiarity as the underlying mechanism instead of broader overall improvement of visual-spatial WM. One important limitation of the present study is the lack of follow-up testing that would inform us about the stability of the observed compensatory training effects and further benefits because of maturation (Henry et al., 2014; see also Rueda et al.,2005, for executive attention training). To conclude, we designed a short intervention for training of processes underlying visual-spatial WM which yielded compensatory effects in preschool children.

FOOTNOTES

[1] Please note that for the Matrix Task there was no sequence to be performed, but different amounts of filled cells had to be indicated. For readability, the term *sequence length* is used consistently.

[2] http://www.cogmed.com/

AUTHOR NOTE

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APPENDIX A

TABLE A1.
Retest Reliability Values for the AGTB Tests in the Examined Age Group (5-8 Years)

Task	Retest Reliability
Word Span (monosyllabic)	.64
Matrix	.51
Corsi Block	.60
Color Span Backwards	.49
Object Span	.51