

Drill and Practice Versus Rehearsal: An Experimental Study of Two Approaches to  
Strengthen Verbal Working Memory and Comprehension among Young Children

By

Peng Peng

Dissertation

Submitted to the Faculty of the  
Graduate School of Vanderbilt University  
in partial fulfillment of the requirements  
for the degree of

DOCTOR OF PHILOSOPHY

in

Special Education

May, 2014

Nashville, Tennessee

Approved:

Douglas Fuchs, Ph.D.

Lynn Fuchs, Ph.D.

Donald Compton, Ph.D.

Emily Tanner-Smith, Ph.D.

## ABSTRACT

Researchers are increasingly interested in working memory (WM) training. However, it remains unclear whether it strengthens WM and comprehension among young children. We investigated whether training verbal WM would improve verbal WM and listening comprehension, and whether training effects differed between 2 approaches: drill and practice vs. rehearsal. Fifty-eight first-grade children were randomly assigned to three groups: WM drill and practice, WM rehearsal training, and the control. The two training groups received one 35-minute session of verbal WM training on each of 10 consecutive school days, totaling 5.8 hours. Both groups demonstrated improvement on trained verbal WM tasks, with the rehearsal group showing greater gains. Compared to controls, the rehearsal group also made significant improvements on an untrained verbal WM task (i.e., Listening Recall) and listening comprehension and retell measures. In comparison to controls, the drill and practice group showed significant improvement in listening comprehension, but not on the retell task. Findings suggest that brief but intensive verbal WM training is feasible with young children and can strengthen their verbal WM and comprehension performance. Caveats and implications for theory and future research are discussed.

*Keywords:* verbal working memory, drill and practice, rehearsal strategy, listening comprehension, young children

## ACKNOWLEDGEMENTS

This work would not have been possible without the support from the Department of Special Education at Vanderbilt. I am especially indebted to Dr. Douglas Fuchs, who have been supportive of my research interests and who worked actively with me to pursue research goals. As my teacher and mentor, Dr. Douglas Fuchs has taught me more than I could ever give him credit for here. He has shown me, by his example, what a good scientist (and person) should be. I am also grateful to each of the members of my dissertation Committee: Dr. Lynn Fuchs, Dr. Donald Compton, and Dr. Emily Tanner-Smith. They has provided me extensive personal and professional guidance and taught me a great deal about scientific research. I would especially thank Loulee Yen, Sam Patton, and Wenjuan Zhang for their help with my dissertation study coordination. Last but not the least; I would like to thank my parents who always love me and support me for the pursuit of my dream.

## TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS .....	iii
LIST OF TABLES .....	v
LIST OF FIGURES .....	vi
Introduction .....	1
Training Tasks and Domain-General vs. Domain-Specific Models of WM.....	2
Training Approaches: Drill and Practice vs. Rehearsal Strategy .....	4
Training Young Children .....	6
Study Aims .....	7
Method .....	8
Participants.....	8
Working Memory Training .....	9
Fidelity of Training Implementation.....	12
Measures of Children’s IQ and Academic Performance.....	12
Pre-and Post-Training Measures.....	13
Data Collection and Analysis Strategy.....	14
Results .....	15
Performance on the Training Tasks and Strategy Use .....	15
Training Effects on Working Memory and Comprehension.....	17
Relation between Strategy Use and Comprehension Improvement.....	20
Discussion .....	22
Caveats and Admonitions.....	23
Implications for Theory.....	25
Future Research.....	26
REFERENCES .....	28

## LIST OF TABLES

1. Demographics and Pre-Training Non-verbal IQ, Word Reading, and Listening Comprehension Performance .....	9
2. Descriptive Statistics on Pre-and Post-Training Measures for the Study Groups .....	18
3. Group Comparisons on Different Outcomes.....	19

## LIST OF FIGURES

1. Rehearsal and drill and practice groups' performances on four WM training task .....	16
2(a). Relation between post-training QRI-Passage Listening Comprehension and percentage rehearsal use in trials involving strategy use during training.....	21
2(b). Relation between post-training QRI-Passage Listening Comprehension and number of different strategies used by the drill and practice group. ....	21

## **Introduction**

Working memory (WM) refers to the capacity to store information temporarily when engaging in cognitively demanding activities (Baddeley, 1986). Compared to short-term memory, WM plays a more influential role in children's academic performance (Baddeley, 1986). This is because many academic tasks involve multiple steps with intermediate solutions that must be remembered for a short time to accomplish the task at hand (Shah & Miyake, 1996). For example, during passage comprehension, children must maintain previously learned information while simultaneously integrating new incoming information as they progress through a text (Cain, Oakhill, & Bryant, 2004).

In recent years, increasing numbers of researchers have explored whether training children's WM indeed strengthens this cognitive ability as well as improves the children's academic performance. Despite such interest and effort, the importance of WM training programs is unclear. Whereas investigators of several studies reported that the training improved children's WM and academic skills, like reading comprehension and mathematics reasoning (e.g., Dahlin, 2011; Holmes, Gathercole, & Dunning, 2009), most have failed to find such effects. The authors of two reviews on WM training (Melby-Lervag & Hulme, 2012; Shipstead, Redick, & Engle, 2012) concluded that, for children between the ages of 8-15, WM training using mostly visual-spatial tasks can improve visual-spatial WM. But, according to these reviews, there were small or no transfer effects to verbal WM or to academic performance.

Several issues should be considered in connection with these mixed findings. First, research on WM training has mostly used visual-spatial tasks. Verbal tasks have been used infrequently. So, one may ask whether training children's verbal WM might improve their verbal WM and academic skills. Second, the predominant training approach has been drill and practice. So, another pertinent question is whether strategy use (e.g., rehearsal) may be an

equally beneficial, or more beneficial, training method? Third, previous studies have focused almost exclusively on children in intermediate grades. The importance of WM training for younger children is largely unknown. Each of these issues will be discussed in turn to provide proper background for the aims of this study.

### **Training Tasks and Domain-General vs. Domain-Specific Models of WM**

One factor that may contribute to WM training's mixed results is the ongoing disagreement about the proper content of the training; specifically, the nature of the training tasks. This uncertainty reflects a longstanding debate about two competing WM models: domain general vs. domain specific (Shah & Miyake, 1996).

Many researchers believe WM is a domain-general construct that directs attention to relevant information, suppresses irrelevant information and inappropriate actions, and coordinates cognitive processes when more than one task must be accomplished simultaneously (e.g., Engle, 2002). Based on this view, the type of tasks (e.g., verbal or visual spatial) used for WM training should not influence training effects.

Others view WM as closely related to the skills and knowledge specific to a given domain (Ericsson & Kintsch, 1995; Unsworth & Engle, 2007). Hence, WM should be trained with respect to domain-specific activities because it is presumed to integrate domain-specific skills, knowledge, and procedures. In accord with this view, verbal WM training should be more effective than visual-spatial WM training for improving performance on verbal WM tasks and verbal-related academic skills.

Although research supports domain-general and domain-specific models (e.g., Ericsson & Kintsch, 1995; Shah & Miyake, 1996), investigations focusing on children's learning favor the domain-specific model. Several studies, for example, have shown that children's visual-spatial WM fails to explain variance in their word reading and passage comprehension (Nation, Adams, Bowyer, Crane, & Snowling, 1999; Seigneuric, Ehrlich, Oakhill, & Yuill,



2000). Verbal WM, by contrast, accounts for variance in performance on these verbal tasks, even when relevant verbal skills (e.g., word reading) are controlled (Cain et al., 2004; Daneman & Carpenter, 1980).

Further support for the domain-specific model comes from reviews of WM deficits among children with learning difficulties (Swanson & Jerman, 2006; Swanson, Zheng, & Jerman, 2009). These reviews indicate that, although such children exhibit WM deficits across verbal and visual-spatial domains, verbal WM deficits appear more important to children with reading difficulties (Swanson et al., 2009); visual-spatial deficits seem more relevant for children with mathematics difficulties (Swanson & Jerman, 2006). Moreover, the researchers of most previous WM training studies with children used visual-spatial WM tasks. Few reported training effects that transferred to verbal WM or academic performance (Shipstead et al., 2012). Taken together, research suggests that training children's verbal WM might strengthen their verbal WM and verbal-related academic skills.

We know of only two studies that actually investigated the effects of verbal WM training with children (Kroesbergen, van't Noordende, & Kolkman, 2014; Swanson, Kehler, & Jerman, 2010). Swanson et al. (2010) reported that compared to a control group, students practicing verbal WM tasks reliably improved their performance on trained WM tasks. No training effects, however, were found on untrained WM tasks. It may be important to note that Swanson et al. (2010)'s training regimen was short in duration (i.e., 15 minutes), fidelity of implementation was not reported, and effects on academic performance were apparently not explored. Kroesbergen et al. (2014) reported that compared to a control group, students practicing verbal WM tasks (numerical WM tasks) did not improve their verbal WM but improved on their numeracy skills. Similar to Swanson et al. (2010), Kroesbergen et al. (2014) did not report the fidelity of implementation either. More importantly, WM training in Kroesbergen et al. (2014) involved intensive numeracy skills training, and thus it is not clear

whether their verbal WM training or numeracy skills training produced effects on children's academic performance (numeracy skills). Taken together, it is still unknown whether training children's verbal WM improves their verbal WM and verbal-related academic skills.

### **Training Approaches: Drill and Practice vs. Rehearsal Strategy**

A second issue that may influence WM training effects is whether drill and practice (i.e., requiring children to repeat WM tasks without strategy instruction; e.g., Klingberg, 2010) is more effective than strategy training (e.g., rehearsing stimuli that must be remembered as in a complex span task; e.g., Swanson et al., 2010). These two training approaches—drill and practice vs. strategy use—reflect different theories about the nature of WM: namely, Capacity Theory (e.g., Engle & Kane, 2004) and Strategy Mediation Theory (e.g., McNamara & Scott, 2001).

**Drill and practice.** A drill and practice approach is based on Capacity Theory, which suggests that an individual's WM is finite. As such, the relation between it and academic performance is dependent upon how much capacity, or WM "space," an individual has available to simultaneously store and process information (Engle & Kane, 2004). In this light, the training of WM can be viewed as increasing the capacity of WM, similar to exercising muscles, which requires repetition, or drill and practice. However, previous WM research employing drill and practice has produced mixed results. Few studies have reported training effects that have transferred to performance on untrained WM tasks or on measures of academic skills (Shipstead et al., 2012).

**Rehearsal strategy.** Strategy Mediation Theory also recognizes that WM is finite. But, unlike Capacity Theory, it suggests that WM performance is determined by the efficiency with which WM capacity is used (e.g., Daneman & Carpenter, 1980; Engle & Marshall, 1983). In this view, the use of strategies plays an important role in improving WM efficiency and may mediate between it and academic skills (McNamara & Scott, 2001). This

perspective is supported by research on WM development, individual differences, and by the training studies.

Research on WM development shows that age differences in WM performance can be explained by older children's more active application of strategies (Hagen, Jongeward, & Kail, 1975). Research on individual differences suggests that strategy use accounts for a reliable amount of variance in WM performance. Such performance is stronger for those who report using a greater number of strategies or more effective strategies (Dunlosky & Kane, 2007; Friedman & Miyake, 2004; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). Finally, WM training in adults show that strategy instruction significantly improves their WM performance, whereas WM training without strategy instruction does not (e.g., McNamara & Scott, 2001).

There is also evidence that strategy use is common in WM and academic performance like comprehension. For example, individuals with strong WM and good comprehension skills are more likely to use strategies when performing WM and reading comprehension tasks than those with poor WM and poor comprehension skills (e.g., Baker, 1994; McNamara & Scott, 2001). Rehearsal appears to facilitate WM and passage comprehension. Adults often rehearse information to prevent forgetting in WM tasks (e.g., McNamara & Scott, 2001). Likewise, a rehearsal strategy is often taught to children to help them improve their passage retell and passage comprehension (e.g., Gersten, Fuchs, Williams, & Baker, 2001; Rose, Cundick, & Higbee, 1983). Moreover, rehearsal is easier to learn and less demanding of resources than other strategies (Turley-Ames & Whitfield, 2003), which suggests that rehearsal training on verbal WM tasks may improve verbal WM and passage comprehension in children.

Two studies investigated effects of rehearsal training on children. St. Clair-Thompson, Stevens, Hunt, and Bolder (2010) trained children to use multiple strategies (including

rehearsal) on short-term memory tasks. Compared to no-treatment controls, children taught multiple strategies improved their score on a verbal WM task. There were no transfer effects to standardized reading and math measures. Swanson et al. (2010) reported that their rehearsal strategy training group showed significantly greater improvement than controls on trained verbal WM tasks, but not on untrained verbal WM tasks. Although findings from these studies suggest rehearsal training may improve performance on verbal WM tasks, they are constrained by study limitations.

In the St. Clair-Thompson et al. (2010) study: (a) strategy training tasks were mainly short-term memory tasks, not verbal WM tasks; (b) because rehearsal was only one of several strategies taught, it is unclear whether rehearsal was an effective, or most effective, strategy; and (c) there were no fidelity of training data presented. For Swanson et al. (2010), the training lasted only 15 minutes. There were no academic measures to explore transfer effects. And, like the St. Clair-Thompson et al. (2010) study, there were no fidelity data. Thus, evidence is still needed on the effects of rehearsal strategy training with verbal WM tasks on verbal WM and academic skills among children.

### **Training Young Children**

We address one last issue concerning WM training: Whether it is efficacious for young children. The vast majority of prior research on WM training has focused on intermediate-grade children. Few training studies have involved younger children, especially with respect to verbal WM training and the possible effects on their academic skills. From a cognitive-developmental perspective, WM training among young children is important because their functional neural networks are relatively plastic and the training may more likely produce desired effects (Shipstead et al., 2012; Wass, Scerif, & Johnson, 2012). Consonant with this view is a review by Melby-Lervåg and Hulme (2012) who found that the visual-spatial WM training of preschoolers produced larger effects than those associated with similar training of

intermediate-grade children.

Such arguments notwithstanding, there is concern that WM tasks may be too challenging for young children (Pickering & Gathercole, 2001). Moreover, because word reading is pivotal to their academic development, and WM correlates *less* strongly than phonological processing with young children's word reading (e.g., Dally, 2006; de Jong & van der Leiji, 1999), WM training may not be as important as word-reading instruction for young children. That said, compared to word reading, verbal WM shows a stronger relationship with comprehension skills (Savage, Lavers, & Pillay, 2007). WM training, therefore, may be more effective in improving young children's comprehension.

### **Study Aims**

The purposes of this study of first grade children were to investigate whether (a) training verbal WM improves verbal WM; (b) such effects transfer to passage listening comprehension; and (c) training effects differ for two approaches: drill and practice vs. rehearsal. The young children participating in drill and practice were presented with complex verbal WM span tasks on which they simultaneously practiced processing and storing verbal information. The rehearsal group was taught to use an explicit rehearsal strategy on the same tasks.

In addition to WM measures, we included several language and cognitive tasks and one academic test (see Method section) to investigate possible effects of verbal WM training. Specifically, we included two untrained verbal WM tasks (i.e., Listening Recall and Counting Recall) to determine whether verbal WM training improved verbal WM. Because rehearsal is closely related to articulation rate and short-term memory (Baddeley, 1986), we measured these language and cognitive functions prior to and immediately following training to explore whether the rehearsal training strengthened them and, if so, whether such improvement mediated training effects. We also collected data on participants' passage listening

comprehension to see if training effects transferred to academic skills.

Our hypotheses were that verbal WM training can be conducted with young children to improve their verbal WM and passage listening comprehension. WM Capacity Theory suggests drill and practice, but not rehearsal, will lead to greater improvement on verbal WM and passage listening comprehension. WM Strategy Mediation Theory leads us to expect rehearsal will be more effective in improving articulation, short-term memory, verbal WM, and passage listening comprehension.

## **Method**

### **Participants**

Participants were 58 children from 13 elementary schools in Nashville, Tennessee. They were originally identified in fall of first grade as struggling readers and were randomly assigned to one of two treatment groups or a control group in an intervention study to improve reading and mathematics skills. Following their 20-week participation in the intervention study, they were tested as part of the present study, and then randomly assigned to three groups: drill and practice training, rehearsal training, or no training (controls). For this study, the groups were comparable in terms of age, gender, race, non-verbal IQ, pre-training academic performance (listening comprehension and word reading), pre-training measures (see Pre- and Post-Training Measures, below), and their previous status (treatment or control) in the intervention study ( $ps > .15$ ). However, there was a marginally significant group difference on pre-training listening comprehension,  $F(2, 55) = 3.00, p = .06$ , with the drill and practice group showing significantly lower performance than controls ( $p = .02$ ).

Table 1 provides demographic information and the children's non-verbal IQ, pre-training listening comprehension, and pre-training word reading performance. These data indicated that the sample's non-verbal IQ (47<sup>th</sup> percentile) and word reading (63<sup>rd</sup> percentile) were in the average range, but their listening comprehension (30<sup>th</sup> percentile) was below-average.

Table 1  
*Demographics and Pre-Training Non-verbal IQ, Word Reading, and Listening Comprehension Performance*

Variable	Rehearsal ( <i>n</i> = 19)			Drill and Practice ( <i>n</i> = 19)			Control ( <i>n</i> = 20)		
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD
Age (years)		7.19	.41		7.09	.36		7.13	.33
Gender (female)	9			7			10		
Race									
African American	9			13			5		
Caucasian	6			2			10		
Hispanic	2			3			3		
Other	2			1			2		
Non-verbal IQ		12.47	6.86		9.16	4.49		10.55	4.86
Word Identification		37.95	11.94		34.68	10.07		38.05	9.59
Listening Comprehension		17.16	5.39		14.95	4.62		18.50	3.55

*Note.* Non-verbal IQ is WASI Matrix Reasoning (Wechsler, 1999); Word Identification is the Word Identification Subtest of the Woodcock Reading Mastery Test-Revised (Woodcock et al., 2001); Listening Comprehension is the Woodcock–Johnson Oral Comprehension subtest (Woodcock, McGrew, & Mather, 2001).

### Working Memory Training

Children randomly assigned to the drill and practice group and rehearsal group participated in 10 WM training sessions, one per day, on 10 consecutive school days. Each session lasted 35 minutes. The training occurred in the children’s schools in the quietest locations available. Twenty-two master’s students in psychology and education programs were deployed as research assistants (RAs). They were randomly assigned to train 3-4 children representing both training groups. All training sessions were one-on-one. That is, the RAs worked with only one child in each training session. Written scripts guided the RAs’ interactions with the children during the training.

**Drill and practice.** In each session, children worked on four complex verbal WM span tasks. Each lasted 8 minutes. The four verbal WM tasks were Counting Figures, Calculation Span, Operation Span, and Puzzles. For the Counting Figures task, children were presented with a 4x4 grid on a piece of paper with two or three types of stimuli (e.g., shapes, cartoon characters, animals) in contrasting colors. There were 36 pages of these grids, each with different stimuli. For every trial (or attempt to recall), children were asked to count one

stimulus (e.g., stars). They were then told to count a second stimulus (e.g., blue triangles). Finally, they were asked to recall the sums of the various stimuli in the order they were counted. Depending on the level of their performance, the children could be asked to count and recall three sums or more.

The Calculation Span task directed the children to solve several simple addition or subtraction problems on flash cards with answers less than 10 (e.g.,  $2+1$ ,  $9-0$ ), and then recall their answers in order. If they had difficulty solving a problem, correct answers were given. Again, depending on the children's performance, they could be asked to recall two or more correct responses.

For Operation Span, children named several sets of cards in each trial. First, they were asked to solve a simple addition or subtraction problem (with answers less than 10) presented on a flash card. Then they had to name a picture card (e.g., tree). Children were asked to recall in order all the picture cards at the end of each trial. If they had difficulty solving the math problem or naming a picture card, correct answers were given. Depending on the level of their performance, the children could be asked to recall two or more picture names.

In the Puzzles activity, children were read six clues (simple sentences no more than 5 words) about a person/place/thing. They were then told to solve the puzzle and use the answer and one or more clues to make a sentence. For example, the RA read these six clues: "I have four legs. I have fur. I have a tail. I like to chase cats. I love to bark. I like to eat bones." The child was then asked, "What am I?" After answering "dog," the child was told to use the answer and at least one clue to make a sentence like, "A dog has four legs." If the children had difficulty constructing a sentence, the RA provided help. If they forgot the clues, the RAs showed them how to make sentences with the clues they did not recall.

**Rehearsal.** The same just-described four tasks were also used for rehearsal training. The main difference between the two groups' training was that the children in the rehearsal group



were explicitly taught a rehearsal strategy and were encouraged to use it during each trial of every task. Specifically, for Counting Figures, Calculation Span, and Counting Span, when the children first encountered numbers or words to be remembered, they were told to say them aloud; say them repeatedly; and say them as fast as possible for 3 seconds. As more stimuli were added in a trial, the children were told to say the new stimulus, as well as other stimuli previously named by them as fast as possible for 3 seconds (or three times if there were more than four stimuli to rehearse). In other words, each time the children encountered a new stimulus to remember, they said it, as well as the previously named stimuli in that trial, as fast as possible for 3 seconds (or three times if there were more than four stimuli to rehearse). When the children forgot to rehearse, or if they rehearsed incorrectly, the RA would provide corrective feedback.

For the Puzzles task, after the children were read each clue, they were asked to identify its key word. In the dog puzzle, the clue was, “I love to bark.” The key word was “bark.” If the children failed to identify it, the RA provided it. Each time the children identified a key word, they were required to say it aloud together with other key words previously identified. After solving the puzzle, the children were told to use the answer and at least one clue to make a sentence. If the children had difficulty constructing a sentence, the RA provided help. If they forgot the clues, the RAs showed them how to make sentences with the clues they did not recall.

For both training groups, and three activities (Counting Figures, Calculation Span, and Counting Span), the WM training was *adaptive*. That is, task difficulty was matched to the children’s memory span performance on a trial-by-trial basis. For Puzzles, the children were encouraged to solve puzzles and recall as many clues as possible in 8 minutes in each session. Points and small prizes (e.g., cartoon stickers) were used to keep the children motivated and on-task.

**Documentation of the training.** For both training groups, the RAs documented the children's performance on each trial of every task on a log form. This form was completed for all sessions. Specifically, for each trial in Counting Figures, Calculation Span, and Operation Span, the RAs recorded the span level (the number of the target words/numbers) on which the children worked; whether they succeeded at this level (correctly recalled all the target words/numbers in order); and the kinds of strategies they used. For each trial of Puzzles, the RAs recorded the number of clues the children recalled independently or used in a sentence, and the strategies they used for remembering them.

### **Fidelity of Training Implementation**

The first author attempted to ensure training fidelity in three ways. First, he conducted a two-day workshop, after which each RA met with him to role-play a training session (with the first author as the child) using a standard protocol. The RAs were required to achieve a fidelity score of 90% or greater on an implementation checklist before they began working with the children. Second, the first author observed each RA during one training session and provided corrective feedback immediately afterward. Third, he met twice with the RAs as a group during the 10-day training period to review training procedures, answer questions from the RAs, and provide support. All training sessions were audiotaped. The first author listened to the complete audio file of one session per child to document average fidelity across all of them for the two training groups. Fidelity was determined to be 96% ( $SD = 3.30\%$ ) and 98% ( $SD = 1.57\%$ ) for the drill and practice and the rehearsal group, respectively. An RA listened to 20% of the audio files and inter-rater agreement between the RA and first author was 82%.

### **Measures of Children's IQ and Academic Performance**

**Non-verbal IQ.** WASI Matrix Reasoning (Wechsler, 1999) is a measure of non-verbal IQ. The child looks at a matrix from which a section is missing and completes it by selecting

among five options. The score is the total number of matrices answered correctly. Wechsler (1999) reported a test-retest reliability coefficient of .90 for 6- and 7-year-olds.

**Listening comprehension.** We used the Woodcock–Johnson Oral Comprehension subtest (Woodcock, McGrew, & Mather, 2001), for which the child listens to short sentences or short passages and provides a missing word. The score is the number of items correctly answered. The test-retest reliability coefficient has been reported as .80 for 6- and 7-year-olds (Woodcock et al., 2001).

**Word reading.** The Word Identification Subtest of the Woodcock Reading Mastery Test-Revised (Woodcock et al., 2001) asks the child to read 100 single words ordered in difficulty. The score is the number of words read correctly. Test-retest reliability for 6- and 7-year-olds has been reported to be .90 (Woodcock et al., 2001).

### **Pre-and Post-Training Measures**

**Counting recall.** This task is an adaptation of the Counting Recall activity from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). It requires the child to count piles of dots; to remember these sums; and to later recall the sums in sequence. There are six trials at each set size (2 to 7 piles of dots per set). The score is the number of trials recalled correctly. Cronbach’s alpha for the sample was .84.

**Listening recall.** This task is an adaptation of the Listening Recall activity from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). The child listens to a series of short sentences, judges the veracity of each sentence by responding “yes” or “no,” and then recalls the final word of each of the sentences in sequence. There are six trials at each set size (1 to 6 sentences per set). The score is the number of trials recalled correctly. Cronbach’s alpha for the sample was .78.

**Digit recall.** This task, too, is adapted from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). The tester orally presents digits ranging from 1 to 9

at the rate of one digit per second. The child is asked to recall the digits in correct serial order. There are six trials at each set size, which range from 1 to 9 digits. The score is the number of trials recalled correctly. Cronbach's alpha for the sample was .82.

**Articulation rate.** This task, administered to assess speed of speech, is adapted from a task developed by Kail (1997). The child repeats a pair of single-syllable words and digits as quickly as possible in 5 seconds. There are three trials of word pairs (fish-pig, book-set, car-spoon) and three trials of number pairs (2-5, 9-3, 1-8). There are two scores. One is the articulation-word rate score: The average number of word pairs the child says correctly in 5 seconds. The second is the articulation-number rate score: The average amount of number pairs the child says correctly in 5 seconds. Mean Cronbach's alpha for the sample for both the articulation-word and articulation-number scores was .84.

**Passage listening comprehension.** This test is part of the Qualitative Reading Inventory (QRI; Leslie & Caldwell, 2001). The tester reads aloud a story of about 250 words. The child retells as much of the story as possible and answers six open-ended comprehension questions. Two equally difficult-to-read stories at the first-grade level were administered at pre- and post-training, respectively. For each story, there are two scores. One is the QRI-Retell score, which reflects the number of things the child recalls about the story. The second is the QRI-Passage Listening Comprehension score, or the number of comprehension questions answered correctly. One RA independently scored each child's retell performance. Another RA independently repeated the scoring for 20% of the sample. Both were "blind" to the study's purposes and to membership in study groups. Inter-rater agreement on the retell score was 99%. The mean split-half reliability coefficient for comprehension questions of the two stories for the sample was .60.

### **Data Collection and Analysis Strategy**

Twenty-two trained RAs conducted all tests in this study. All tests were conducted

individually in a quietest place available at school. All RAs were blind to children's training membership during pre-and post-training testing points. All pre-and post-training tests were conducted in one session that lasted approximately 60 min.

For data analyses, we first plotted children's performance across time on each WM training task, and we summarized their strategy use. Next, we explored distributions of performance on each measure (e.g., SD, skewness, kurtosis). Because we drew our sample from 13 schools, we calculated intra-class correlation coefficients to evaluate school effects on each post-training measure. To account for medium or large school variance, we used multilevel modeling (Raudenbush & Bryk, 2002) with Level-1 indicating a child level and Level-2 a school level. Then, we used hierarchical regression-based analysis to examine the treatment effects (i.e. no-strategy-instruction vs. control; rehearsal vs. control; no-strategy-instruction vs. rehearsal) on outcome measures controlling for pretreatment performance on the same measures. Moreover, we examined whether children's pre-training non-verbal IQ, academic skills and WM skills moderate training effects and whether training-related improvement on WM, short-term memory, or articulation mediated training-related improvement on passage comprehension skills.

## **Results**

### **Performance on the Training Tasks and Strategy Use**

Based on information from the training logs, we plotted children's performance across time on each WM training task, and we summarized their strategy use. Figure 1 displays rehearsal and drill and practice children's improvement in terms of the highest span achieved (the highest number of words/numbers/clues recalled correctly) on each of the four verbal WM tasks. The rehearsal group demonstrated statistically significant improvement on each task across 10 sessions, slope (improvement rate) = .15~.46,  $ps < .01$ . Their greatest improvement was on Counting Figures, slope = .46,  $p < .001$ ; their least improvement was on

Puzzles, slope = .15,  $p = .001$ . The drill and practice group showed statistically significant improvement on only Calculation Span, slope = .11,  $p = .02$ , and Puzzles, slope = .10,  $p = .02$ . The rehearsal group demonstrated significantly greater improvement than the drill and practice group on all WM training tasks,  $F(1, 36) = 19.63 \sim 36.25$ ,  $ps < .001$ , except on Puzzles,  $F(1, 36) = .98$ ,  $p = .33$ .

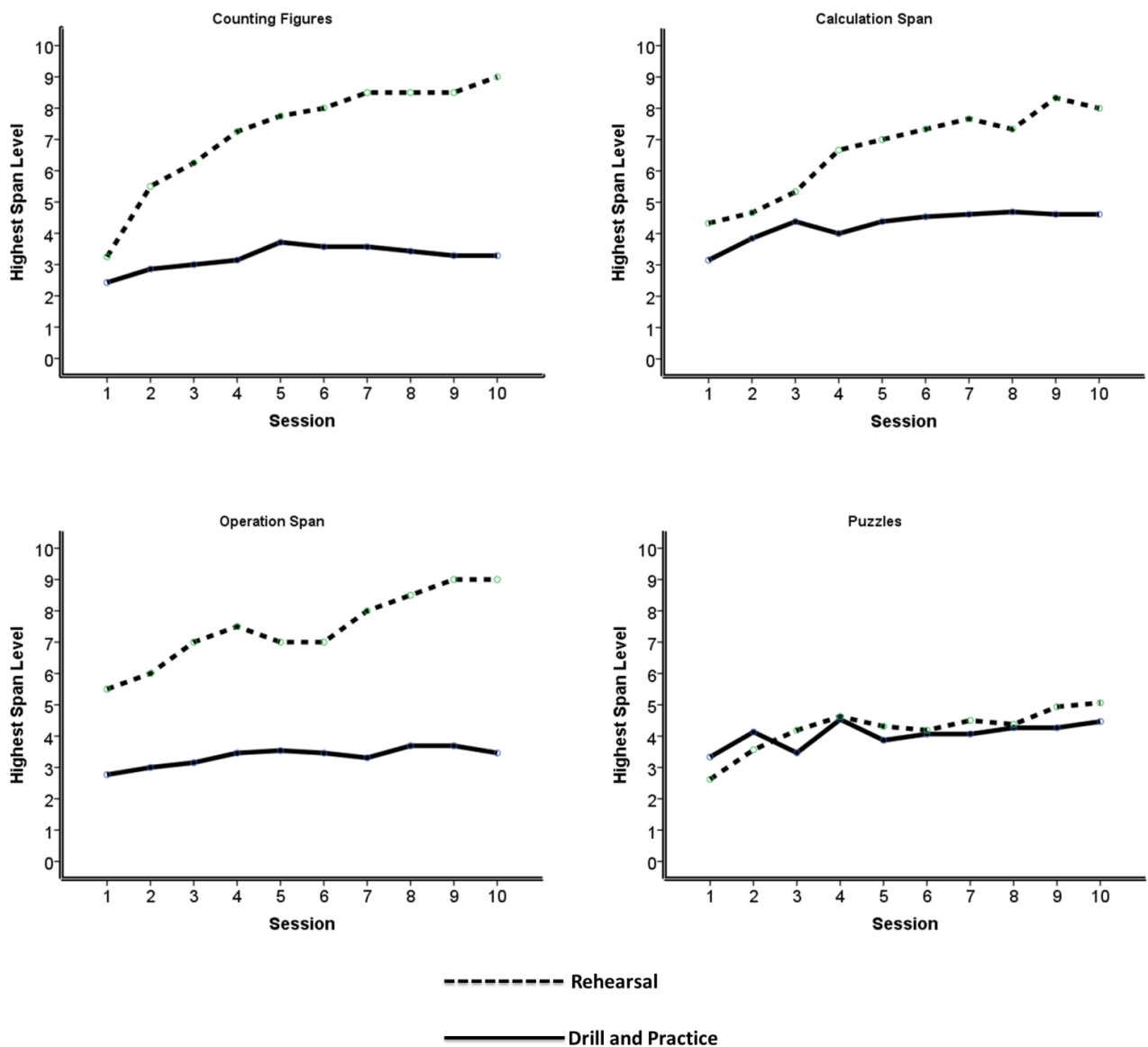


Figure 1. Rehearsal and drill and practice groups' performances on four WM training task

On average, the children in the rehearsal group used strategies during 99% of all training trials. Among these trials, 89% (of the 99%) involved rehearsal, 5% involved a counting strategy (i.e., children used their fingers to track the number of words/numbers), 5% involved a visual strategy (i.e., children memorized/pointed to the position of the word/number flash cards), 1% involved a semantic strategy (i.e., children put the to-be-remembered words/numbers in a sentence), and 0.2% involved other strategies (e.g., children chunked words/numbers).

Because we did not prevent members of the drill and practice group from relying on strategies, we observed them using strategies in 28% of all training trials. Among these, 59% (of the 28%) involved rehearsal, 32% showed evidence of a counting strategy, 6% included a visual strategy, 3% involved a semantic strategy, and 0.4% reflected use of other strategies. Therefore, the drill and practice group's average use of rehearsal across trials was 17% (59% of 28%). The corresponding average percentage for the rehearsal group was 88% (89% of 99%). In other words, although the drill and practice group used rehearsal, its use of the strategy was considerably less frequent than the rehearsal group's use of it.

### **Training Effects on Working Memory and Comprehension**

**Preliminary analyses.** We first explored distributions of performance on each measure (e.g., SD, skewness, kurtosis). Generally, performance was normally distributed at pre- and post-training (see Table 2). Because we drew our sample from 13 schools, we calculated intra-class correlation coefficients to evaluate school effects on each post-training measure. Schools explained a small-to-large proportion of the variance (0.1% ~ 27%). To account for this variance, we used multilevel modeling (Raudenbush & Bryk, 2002) with Level-1 indicating a child level and Level-2 a school level.

Table 2  
*Descriptive Statistics on Pre-and Post-Training Measures for the Study Groups*

Measure	Rehearsal						Drill and Practice						Control					
	Pre-training			Post-training			Pre-training			Post-training			Pre-training			Post-training		
	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis
Listening Recall	7.05 (3.46)	.41	.37	9.00 (3.30)	-.08	.40	6.37 (3.39)	.32	-.22	7.79 (2.76)	.51	-.69	6.60 (3.32)	.51	-.98	7.60 (3.10)	.65	-.16
Counting Recall	12.37 (3.98)	-.01	-.77	14.84 (3.44)	-.47	1.44	12.26 (3.91)	-.26	-.64	15.58 (3.99)	1.12	1.16	13.10 (4.98)	.54	1.22	14.20 (4.88)	-.47	.22
Articulation-word rate	5.16 (1.17)	-.26	-.96	6.02 (1.21)	-.18	-1.41	4.66 (.98)	.36	-.21	5.68 (1.11)	-.35	.20	5.21 (1.19)	.29	-.09	5.90 (1.05)	.52	.42
Articulation-number rate	6.72 (1.72)	-.32	-1.24	8.14 (1.40)	-.32	-.76	6.65 (1.07)	-.67	-.69	7.47 (1.19)	-.97	1.33	6.83 (1.51)	-.72	-.37	7.58 (1.39)	.10	-.91
Digit Recall	24.05 (4.59)	1.37	4.04	23.16 (4.27)	.16	.05	23.11 (3.76)	-.03	-.70	22.68 (3.15)	1.08	3.64	23.95 (3.50)	-.62	-.36	23.90 (3.67)	-.08	-.93
QRI-Retell	10.95 (7.18)	.58	-.58	14.63 (7.44)	.23	.58	10.79 (5.72)	.13	-.37	11.11 (6.43)	.46	1.20	11.68 (7.34)	1.07	1.27	11.50 (4.56)	.12	-.35
QRI-Passage Listening Comprehension	4.26 (1.37)	-.53	.06	3.95 (1.54)	-.81	.96	4.26 (1.24)	-.37	-.65	3.63 (1.74)	-.35	-.58	4.40 (1.39)	-.29	-1.12	3.40 (1.14)	.51	-.19

*Note.* Listening Recall is adapted from the Listening Recall from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001); Counting Recall is adapted from the Counting Recall from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001); Articulation-word rate is the word rehearsal speed adapted from Kail (1997); Articulation-number rate is number rehearsal speed adapted from Kail (1997); Digit Recall is adapted from the Digit Recall from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001); QRI-Retell is the retell score from the Qualitative Reading Inventory (Leslie & Caldwell, 2001); QRI-Passage Listening Comprehension is the comprehension score from the Qualitative Reading Inventory (Leslie & Caldwell, 2001).

We increased statistical power by creating two sets of dummy variables to examine three group comparisons: (a) rehearsal vs. control, (b) drill and practice vs. control, and (c) rehearsal vs. drill and practice (see Stanovich & Siegel, 1994, for a rationale). The first set included dummy variables that compared the rehearsal group to controls (rehearsal = 1; drill and practice = 0; control = 0), and the drill and practice group to controls (rehearsal = 0; drill and practice = 1; control = 0) (Cohen et al., 2003). The second set subsumed two more dummy variables; one comparing the rehearsal group to the drill and practice group (rehearsal = 1; drill and practice = 0; control = 0); the second comparing controls to the drill and practice group (rehearsal = 0; drill and practice = 0; control = 1) (Cohen et al., 2003).

**Training effects.** We compared the two training groups on the post-training measures of WM, short-term memory, articulation rate, QRI-Retell, and QRI-Passage Listening Comprehension, controlling for pre-training performance on the same measures. Because there were marginally statistically significant group differences on listening comprehension at pre-training ( $p = .06$ ), we also controlled pre-training listening comprehension for group comparisons on post-training QRI-Retell and QRI-Passage Listening Comprehension.



Table 3 shows comparisons among the three study groups on each outcome. The rehearsal group outperformed controls on an untrained verbal WM task (i.e., Listening Recall), Hedge's  $g = .72, p = .03$ , QRI-Retell, Hedge's  $g = .68, p = .04$ , and QRI-Passage Listening Comprehension, Hedge's  $g = .72, p = .03$ . The rehearsal group also (marginally) outperformed controls on the articulation-number rate, Hedge's  $g = .61, p = .06$ . The drill and practice group's performance was significantly stronger than controls on QRI-Passage Listening Comprehension, Hedge's  $g = .76, p = .02$ , but not on any other measure. While there were no significant differences between the two training groups, the rehearsal group's performance on an untrained verbal WM task (i.e., Listening Recall), articulation-number rate, and QRI-Retell was superior to the drill and practice group's performance in terms of moderate effect sizes (Hedge's  $g = .49\sim.59$ ; see Table 3).

Table 3  
*Group Comparisons on Different Outcomes*

Measures	Rehearsal vs. Control			Drill and Practice vs. Control			Rehearsal vs. Drill and Practice			Proportion of Residual Variance in the school level
	<i>Coeff</i>	SE	ES	<i>Coeff</i>	SE	ES	<i>Coeff</i>	SE	ES	
Listening Recall	1.50*	.67	.72	.49	.67	.24	1.01	.67	.49	.22*
Counting Recall	.95	1.25	.24	1.6	1.26	.45	-.81	1.26	.21	.08
Articulation-word rate	.21	.29	.23	.13	.29	.15	.07	.29	.08	.15*
Articulation-number rate	.63+	.33	.61	.03	.33	.03	.60+	.33	.59	.08
Digit Recall	-.82	.76	-.34	-.57	.77	-.24	-.25	.77	.10	.06
QRI-Retell	3.86*	1.82	.68	.87	1.89	.15	2.99	1.84	.53	0
QRI-Passage Listening Comprehension	.85*	.38	.72	.95*	.40	.76	-.10	.39	.08	.09

*Coeff* = coefficient in the HLM model, SE = Standard Errors of the coefficient, ES = Effect Size (Hedge's  $g$ ).  
\*  $p < .05$ , +  $p < .08$ .

Because children in the rehearsal group significantly improved their verbal WM (i.e., Listening Recall), QRI-Retell, and QRI-Passage Listening Comprehension, we next examined whether training-related verbal WM improvement mediated the improvement on QRI-Retell and QRI-Passage Listening Comprehension. However, because training related

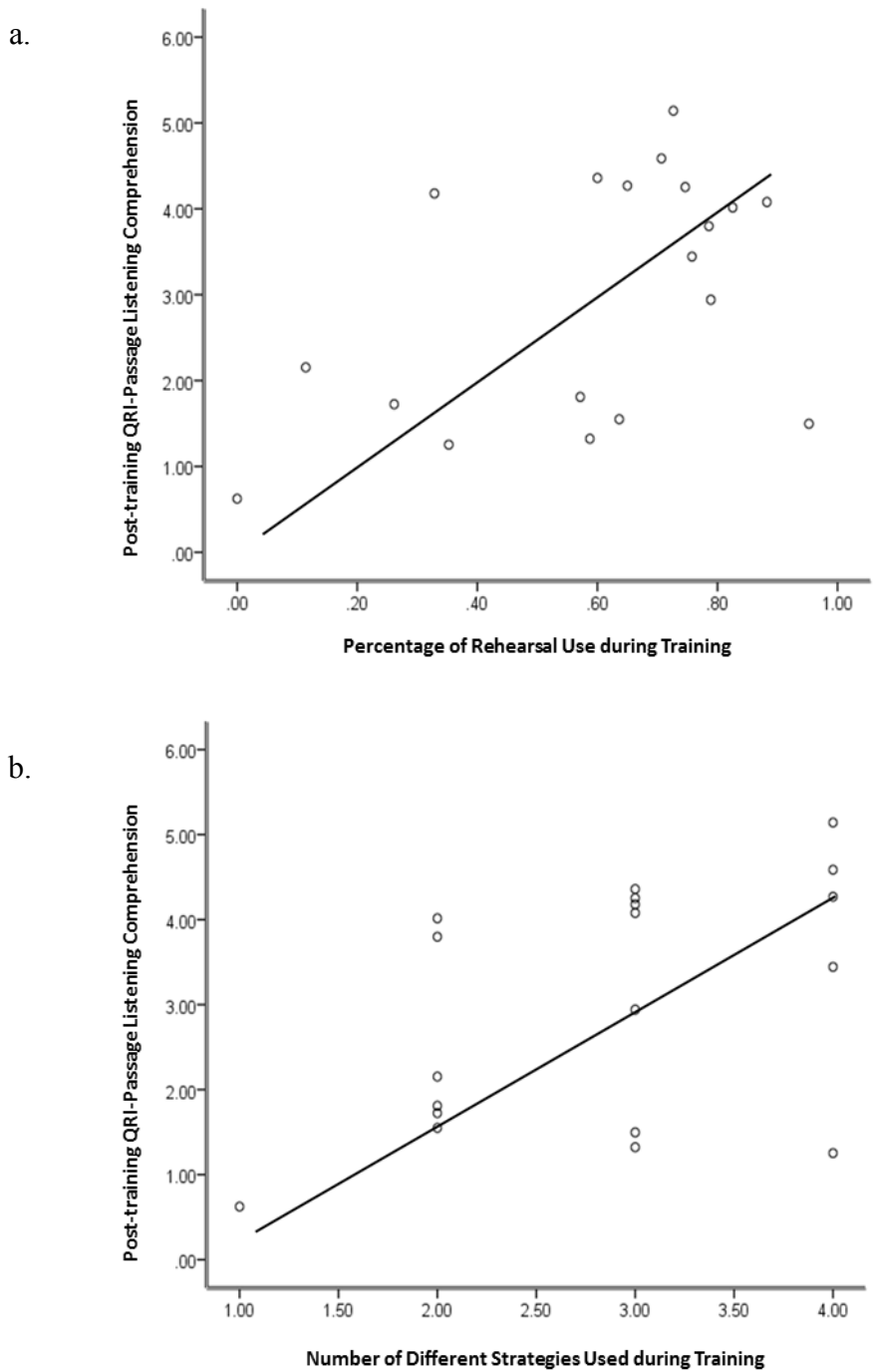
verbal WM improvement significantly correlated with QRI-Retell and QRI-Passage Listening Comprehension improvement ( $ps > .13$ ). Thus, the training-related verbal WM did not mediate group difference on QRI-Retell and QRI-Passage Listening Comprehension.

Moreover, the children in this study varied on their pre-training non-verbal IQ, academic skills and WM skills. So, we examined whether pre-training non-verbal IQ, academic skills, such as word reading and listening comprehension, and pre-training WM skills moderated the training effects. Results indicated that pre-training non-verbal IQ, word reading, passage comprehension, and WM did *not* significantly moderate training effects on any outcome measures ( $ps > .10$ ).

Because our sample of first-grade children had been part of a prior intervention study, we controlled for children's previous training status (covarying out children's previous training status), and our results did not change.

### **Relation between Strategy Use and Comprehension Improvement**

As mentioned, across the drill and practice trials, children demonstrated strategy use in 28% of them. To explore relations between such strategy use and the children's improvement on passage listening comprehension, we looked at whether strategy use in the drill and practice group was correlated with their QRI-Passage Listening Comprehension improvement. After covarying the pre-training QRI-Passage Listening Comprehension and pre-training listening comprehension, rehearsal use and the number of strategy types used during training significantly and positively correlated with the post-training QRI-Passage Listening Comprehension ( $r = .49$  and  $.53$ ,  $ps < .05$ ). Scatter plots indicated no evidence of outliers exerting undue influence on these correlations (See Figure 2). Thus, for the drill and practice children, the greater the reliance on rehearsal and the greater the number of different strategies employed during training, the more likely we were to see improvement on the QRI-Passage Listening Comprehension as compared to controls.



*Figure 2.* (a) Relation between post-training QRI-Passage Listening Comprehension and percentage rehearsal use in trials involving strategy use during training. (b) Relation between post-training QRI-Passage Listening Comprehension and number of different strategies used by the drill and practice group.

*Note.* Pre-training listening comprehension and pre-training QRI-Passage Listening Comprehension were controlled in the correlation analysis.

## Discussion

Few studies of WM training have explored the consequences of verbal WM training on verbal WM tasks and passage listening comprehension measures; or enlisted young children as study participants; or compared different approaches to train verbal WM in the same study. In this randomized control trial, we did all three. We examined whether intensive (2-week, 10-session, 5.8 hours) training of verbal WM would strengthen verbal WM and passage listening comprehension in first-grade children, and we explored whether drill and practice and rehearsal exerted differential effects.

Despite our rather small sample size and underpowered analyses, both training groups showed improvement on WM training tasks. The rehearsal group also strengthened its performance in contrast to controls on an untrained verbal WM task (i.e., Listening Recall; Hedge's  $g = .72$ ). Moreover, for both drill and practice and rehearsal groups, training effects appeared to transfer to one or more measures of listening comprehension. Specifically, rehearsal training strengthened children's QRI-Retell (Hedge's  $g = .68$ ) and QRI-Passage Listening Comprehension (Hedge's  $g = .72$ ). Drill and practice training strengthened group members' QRI-Passage Listening Comprehension (Hedge's  $g = .76$ ). The superior performances of the two training groups versus controls on WM tasks and listening comprehension measures do not seem attributable to articulation speed or verbal short-term memory because members of the training groups did not show significant gains in these functions when they were compared to controls. Although there were no statistically significant differences between the two training groups on any WM or comprehension measure, there were moderately large effect size differences favoring the rehearsal group on an untrained verbal WM task (i.e., Listening Recall), QRI-Retell, and articulation speed (Hedge's  $g = .49\sim.59$ ; see Table 3).

An unexpected finding was that rehearsal-group children did not show improvement on

the Counting Recall task. One possible explanation begins with Counting Figures, a task similar in format to Counting Recall. On Counting Figures, we purposely gave children sufficient rehearsal time, signaling them if necessary to use the rehearsal strategy. For Counting Recall, by contrast, we used a standard and quick-paced administration that reduced time and opportunity for rehearsal. Thus, the relatively fast-paced administration of Counting Recall may have inhibited rehearsal for rehearsal group members.

### **Caveats and Admonitions**

Whereas findings suggest that training verbal WM— especially with rehearsal — strengthens young children’s verbal WM and passage listening comprehension, they are not without important caveats. These are of two kinds. The first is a set of study limitations, the most important of which may be that we did not explore possible changes in attention (or changes in other possibly relevant cognitive functions) during the study that might have mediated group differences on verbal WM and comprehension improvement. Children in the two training groups were frequently required to work with long lists of words and numbers. Research suggests that as one increases the load on short-term memory one is also requiring greater amounts of attention (e.g., Unsworth & Engle, 2007). Thus, our WM training may have simultaneously and inadvertently involved attention training. Hence, stronger attention is a reasonable and competing explanation for the training groups’ superior performance versus controls. Similarly, because children in the rehearsal group were likely to encounter longer lists of words and numbers than those in the drill and practice group, we may have been strengthening the rehearsal group’s attention relative to both controls and drill and practice children.

Because attention is closely related to WM and comprehension, and attention training can improve reading comprehension (Solan, Shelley-Tremblay, Ficarra, Silverman, & Larson, 2003), future studies of WM training should explore the importance of WM and attention

(and perhaps additional cognitive abilities). That said, our failure to separate the influence of WM from that of attention in this investigation should not diminish, we believe, the importance of the finding that our training seemed to transfer to improved performance on listening comprehension measures.

A second study limitation is that the amount of WM training (one 35-minute session per day on 10 consecutive school days) may have been insufficient for children in the drill and practice training group. In comparison to the rehearsal group, these children demonstrated smaller but statistically significant improvement on WM training tasks (i.e., Calculation Span and Puzzles). Also, although the drill and practice group did not show reliable post-training improvement on untrained verbal WM tasks (i.e., Listening Recall and Counting Recall), the effect sizes (Hedge's  $g = .24 \sim .45$ ) reflected small-to-moderate improvement in comparison to controls. Thus, training verbal WM by drill and practice may prove effective for improving young children's verbal WM if the training program were of longer duration.

A third study limitation is that we conducted multiple statistical comparisons, which can increase the possibility of type I error (although the effect sizes for many of our group comparisons were moderate to large in magnitude). Fourth, although study participants were initially identified as struggling readers in fall of their first-grade year for a different investigation, by the time they entered the current study (in late spring), their mean reading performance was in the average range. Thus, whatever importance is attributed to our findings must be qualified by this fact. We do not assume that study outcomes will necessarily generalize, say, to young children struggling to read at the word level.

In addition to this set of study limitations, another kind of necessary caveat is that our findings are inconsistent with two previous studies that involved rehearsal training. St. Clair-Thompson et al. (2010) reported that teaching children multiple strategies on short-term memory tasks improved their performance on verbal WM but not on standardized reading

and math measures. Swanson et al. (2010) found that students practicing rehearsal on verbal WM tasks made statistically significant improvements on the trained, but not on the untrained, tasks. Differences between our findings and those of the two prior studies may be due to different study methods. St. Clair-Thompson et al. taught rehearsal as but one of several strategies; and they focused on short-term memory tasks. Swanson et al. provided only 15 minutes of rehearsal training. Thus, in comparison to these two rehearsal studies, our verbal WM training appears to have been more narrowly focused and intensive and was conducted with strong (documented) fidelity to our training protocols.

### **Implications for Theory**

Caveats notwithstanding, our results seem to shed some light on at least two important theoretical considerations. First, our study participants' fluent rehearsal of important information while dealing with distractions (e.g., calculation or counting) inherent in the verbal WM tasks, may have created more verbal WM capacity for processing and remembering information simultaneously. Our data and this inference are consonant with Strategy Mediation Theory, which suggests strategy use can lead to more efficient use of WM. Because the comprehension process is similar to that of verbal WM (Cain et al., 2004), and because rehearsal appears to be an effective strategy in comprehension and verbal WM (e.g., Gersten et al., 2001; Rose et al., 1983; Turley-Ames & Whitfield, 2003), our results suggest (however tentatively) that if children rehearse information fluently as they listen to (or read) a passage, they are more likely to remember the information and integrate it with previous information, producing stronger comprehension.

We remind the reader in this regard that we observed children in the drill and practice group also using strategies—for 28% of total trials, 59% of which involved rehearsal. That is, at least some young children use rehearsal during verbal WM training without explicit instruction to do so, presumably because it comes “naturally” to them and is less cognitively

demanding than other strategies (Turley-Ames & Whitfield, 2003). Moreover, our drill and practice children's use of rehearsal positively correlated with their improvement on passage listening comprehension (and no obvious "outliers" were driving this correlation; see Figure 2). These observations, together with the rehearsal group's strong showing, indicate that rehearsal used in conjunction with verbal WM tasks may lead to improved comprehension among young children.

A second theoretical implication involves previous reviews of WM training. These reviews indicate that attempts to strengthen visual-spatial WM have had small or no effect on improving children's verbal WM or their verbal-related academic performance (Shipstead et al., 2012). Together with our results, they suggest that the efficacy of WM training is influenced by the nature of the training task: Verbal WM training may be more fruitful than visual-spatial WM training when desired outcomes for children include verbal WM and comprehension. This is consistent with a domain-specific model of WM, which suggests WM is closely related to the skills and knowledge specific to a given domain (Ericsson & Kintsch, 1995; Unsworth & Engle, 2007). Thus, verbal WM training should be more effective than visual-spatial WM training for improving performance on verbal WM tasks and verbal-related academic skills.

### **Future Research**

Previous research indicates that visual-spatial WM training exerts stronger effects among young children than older children (e.g., Melby-Lervåg & Hulme, 2012). This, together with current findings, suggests the importance of cognitive skills training at a relatively early age. This suggestion is consonant with a view that young children's functional neural networks are relatively plastic and that the training of cognitive skills is more likely to produce desired effects than that among older children (Wass, Scerif, & Johnson, 2012). Researchers might more often involve young children in their research on cognitive training.



In a similar vein, our findings may have implications for intervening with young children with severe learning problems. Research indicates that first-grade children's cognitive characteristics contribute to the prediction of their reading comprehension and learning disability status in the intermediate grades (e.g., D. Fuchs, Compton, Fuchs, Hamlett, & Lambert, 2012). Between 5% and 10% of the general population do not respond to generally effective academic (reading or math) instructions (e.g., D. Fuchs, Fuchs, & Stecker, 2010; Wanzek & Vaughn, 2007), and their non-responsiveness is closely associated with, or caused by, deficits in cognitive skills such as WM, processing speed, and non-verbal IQ (e.g., D. Fuchs et al., 2012; L. Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlett, 2005). Considering our sample had below-average comprehension skills (30<sup>th</sup> percentile), our findings suggest that cognitive skills training may be an important supplement to academic instructions for young children with learning difficulties. Intervention researchers may consider the training of cognitive skills or, maybe more properly, a combination of cognitive skills training and academic instructions to boost the academic performance of young children with learning problems, especially those who have shown inadequate responsiveness to generally effective instructions.

## REFERENCES

- Baddeley, A. D. (1986). *Working memory*. New York: Oxford Univ. Press.
- Baker, L. (1994). Fostering metacognitive development. In H. Reese (Ed.), *Advances in child development and behavior* (Vol. 25, pp. 201-239). San Diego: Academic Press.
- Cain, K., Oakhill, J., & Bryant, P. E. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology, 96*, 31-42.
- Dahlin, K. I. E. (2011). Effects of working memory training on reading in children with special needs. *Reading and Writing, 24*, 479-491.
- Dally, K. (2006). The influence of phonological processing and inattentive behavior on reading acquisition. *Journal of Educational Psychology, 98*, 420-437.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.
- de Jong, P. F., & van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a Dutch latent variable longitudinal study. *Journal of Educational Psychology, 91*, 450-476.
- Dunlosky, J., & Kane, M. J. (2007). The contributions of strategy use to working memory span: A comparison of strategy assessment methods. *Quarterly Journal of Experimental Psychology, 60*, 1227-1245.
- Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*, 19-23.
- Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation* (pp. 145-199). New York: Academic Press.
- Engle, R., & Marshall, K. (1983). Do developmental changes in digit span result. from

- acquisition strategies? *Journal of Experimental Child Psychology*, 36 429-436.
- Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102, 211-245.
- Friedman, N. P., & Miyake, A. (2004). The Reading Span test and its predictive power for reading comprehension ability. *Journal of Memory and Language*, 51, 136-158.
- Fuchs, D., Compton, D. L., Fuchs, L. S., Hamlett, C. L., & Lambert, W. (2012). First-grade cognitive abilities as long-term predictors of reading comprehension and disability status. *Journal of Learning Disabilities*, 45, 217-231.
- Fuchs, D., Fuchs, L. S., & Stecker, P. M. (2010). The “blurring” of special education in a new continuum of general education placements and services. *Exceptional Children*, 76(3), 301-323.
- Fuchs, L. S., Compton, D. L., Fuchs, D., Paulsen, K., Bryant, J. D., & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*, 97, 493-513.
- Gersten, R., Fuchs, L. S., Williams, J. P., & Baker, S. (2001). Teaching reading comprehension strategies to students with learning disabilities: A review of research. *Review of Educational Research*, 71, 279-320.
- Hagen, J. W., Jongeward, R. H., & Kail, R. V. (1975). Cognitive perspectives on the development of memory. *Advances in Child Development and Behavior*, 10, 57-101.
- Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, 12(4), F9-F15.
- Hoover, W. & Gough, P.B. (1990). The simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, 2, 127-160.
- Kail, R. (1997). Phonological skill and articulation time independently contribute to the

- development of memory span. *Journal of Experimental Child Psychology*, 67(1), 57-68.
- Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, 14, 317-324.
- Kroesbergen, E. H., Van't Noordende, J. E., & Kolkman, M. E. (2014). Training working memory in kindergarten children: Effects on working memory and early numeracy. *Child Neuropsychology*, 20, 23-37.
- Leslie, L., & Caldwell, J. (2001). *Qualitative reading inventory -3*. New York: Addison Wesley Longman.
- Melby-Lervåg, M., & Hulme, C. (2012). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, 49, 270-291.
- McNamara, D. S., & Scott, J. L. (2001). Working memory capacity and strategy use. *Memory & Cognition*, 29, 10-17.
- Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology*, 73, 139-158.
- Pickering, S., & Gathercole, S. E. (2001). *Working Memory Test Battery for Children for children (WMTB-C)*. Psychological Corporation.
- Raudenbush, S.W., & Bryk, A.S. (2002). *Hierarchical Linear Models: Applications and Data Analysis Methods*. Thousand Oaks, CA: Sage.
- Rose, M. C., Cundick, B. P., & Higbee, K. L. (1983). Verbal rehearsal and visual imagery: Mnemonic aids for learning disabled children. *Journal of Learning Disabilities*, 16, 352-354.
- Savage, R., Lavers, N., & Pillay, V. (2007). Working memory and reading difficulties: What we know and what we don't know about the relationship. *Educational Psychology Review*, 19, 185-221.

- Seigneuric, A., Ehrlich, M.-F., Oakhill, J. V., & Yuill, N. M. (2000). Working memory resources and children's reading comprehension. *Reading and Writing, 13*, 81-103.
- Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*, 4-27.
- Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is Working Memory Training Effective? *Psychological Bulletin, 138*, 628-654.
- Solan, H. A., Shelley-Tremblay, J., Ficarra, A., Silverman, M., & Larson, S. (2003). Effect of attention therapy on reading comprehension. *Journal of Learning Disabilities, 36*, 556-563.
- Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core difference model. *Journal of Educational Psychology, 86*, 24-53.
- St. Clair-Thompson, H. L., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology, 30*, 203-219.
- Swanson, H. L., Kehler, P., & Jerman, O. (2010). Working memory, strategy knowledge, and strategy instruction in children with reading disabilities. *Journal of Learning Disabilities, 43(1)*, 24-47.
- Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: A selective meta-analysis of the literature. *Journal of Learning Disabilities, 42*, 260-287.
- Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language, 49(4)*, 446-468.
- Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from

secondary memory. *Psychological Review*, 114, 104-132.

Wanzek, J., & Vaughn, S. (2007). Research-based implications from extensive early reading interventions. *School Psychology Review*, 36, 541-561.

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory – Is younger, better? *Developmental Review*, 32, 360-387.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: Psychological Corporation.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III*. Itasca, IL: Riverside Publishing.