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Working memory capacity and strategy use

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In this study, we examine the role of strategy use in working memory (WM) tasks by providing short-term memory (STM) task strategy training to participants. In Experiment 1, the participants received four sessions of training to use a story-formation (i.e., chaining) strategy. There were substantial improvements from pretest to posttest (after training) in terms of both STM and WM task performance. Experiment 2 demonstrated that WM task improvement did not occur for control participants, who were given the same amount of practice but were not provided with strategy instructions. An assessment of participants' strategy use on the STM task before training indicated that more strategic participants displayed better WM task performance and better verbal skills. These results support our hypothesis that strategy use influences performance on WM tasks.

Working memory (WM) refers to a limited capacity, short-term cognitive system for processing and storing information. It serves as a gateway and workroom for a multitude of cognitive processes. Indeed, WM seems to play a critical role in most higher level cognitive tasks, such as learning, reasoning, and comprehension (see, e.g., Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Engle, Carullo, & Collins, 1991; Just & Carpenter, 1992; Kyllonen & Christal, 1990). Complex reasoning and comprehension tasks also rely heavily on other factors, such as knowledge and strategy use (e.g., Bransford & Johnson, 1972; Holmes, 1983; Kavale & Schreiner, 1979; McNamara & Kintsch, 1996a; Palincsar & Brown, 1984). However, researchers have generally assumed that WM tasks measure a construct that is separate from strategy use and that performance on these tasks is largely strategy free (e.g., Engle, Cantor, & Carullo, 1992; Engle, Nations, & Cantor, 1990; Just & Carpenter, 1992). The purpose of this study is to further examine the role of strategy use in WM task performance. We do so by examining whether strategy training and participants' reported strategy use improve performance on WM tasks.

Measures of WM capacity are dual tasks, including a *processing* task and a *storage* task. The storage task is generally a short-term memory (STM) task in which the participant is presented, and then immediately recalls, a list of words. The processing task is intended to occupy WM capacity, thus providing a measure of how much capacity remains to successfully encode the target words. For example, the reading span task requires reading series of two to six sentences and subsequently recalling either the last word of each sentence (e.g., Daneman & Carpenter, 1980) or an unrelated word presented after each sentence (e.g., Turner & Engle, 1989). Correlational studies relating measures of WM capacity and measures of verbal ability have indicated that skilled readers recall more words in WM tasks than do less skilled readers. The strength of correlations between WM and verbal skills show a wide range but generally hover in the range of .30 to .60 (e.g., Daneman & Merikle, 1996). Hence, many researchers have concluded that greater WM capacity allows the reader to complete more of the complex cognitive processes involved in reading (e.g., Just & Carpenter, 1992).

There are several variations to theories of WM and the effects of an individual's capacity on higher level processing tasks, such as reading (e.g., Daneman & Tardif, 1987; Engle et al., 1992; Just & Carpenter, 1992). Most of these theories assume that there exists a stable construct, such as capacity, activation resources, or attention span, that causally constrains an individual's abilities. For example, when encountering a pronoun, a reader who performs well on WM tasks (and thus is presumed to have greater WM capacity) is more likely to recall the noun referent and, hence, better comprehends the passage. According to a capacity-oriented theory, skilled readers make more text-based inferences because the two sources of information are both available in WM. Thus, an individual who has greater WM capacity is able to hold in consciousness more information relevant to completing complex tasks, such as reading, and shows better performance as a result (e.g., Budd, Whitney, & Turley, 1995; Perfetti, 1989; Whitney, Ritchie, & Clark, 1991).

An alternative explanation is that better readers make more inferences because they are strategic, they know how to make the inferences, and they know when the inferences are necessary. This explanation is supported by research showing that skilled readers are more strategic (e.g., Baker, 1994; Garner, 1987; Long & Golding, 1993;

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Long, Oppy, & Seely, 1994; Oakhill, 1982, 1983) and by research showing that less skilled readers benefit from strategy training (e.g., Chi, de Leeuw, Chiu, & LaVancher, 1994; Cornoldi & Oakhill, 1996; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson, 1983; Kucan & Beck, 1997; McNamara & Scott, 1999; Palincsar & Brown, 1984; Paris, Cross, & Lipson, 1984; Yuill & Oakhill, 1988). Hence, strategic readers may also be more likely to use strategies when performing WM tasks. That is, strategic readers may also be strategic memorizers. If this were the case, strategy use might contribute to correlations between WM capacity and verbal abilities.

Along these lines, Ericsson and Kintsch (1995) proposed that skilled memory performance is due to the use of *long-term working memory* (LTWM), which is a more efficient WM with faster access to long-term memory (LTM) than normal WM. Typical WM retrievals from LTM require 1–2 sec, whereas LTWM retrievals require approximately 400 msec (e.g., McNamara & Kintsch, 1996b). This fast access results from using cues in STM to activate retrieval structures that directly retrieve information from LTM. Experts are able to use LTWM to bypass STM processing limitations, because experience within a particular domain leads to enriched knowledge structures and information retrieval strategies. LTWM retrieval structures and strategies may be particularly important to WM task performance, because of the need to switch attention repeatedly between processing and storage tasks. LTWM would allow an individual to more efficiently reaccess the words from LTM that were no longer available in STM. Hence, a person using strategies would appear to have greater WM capacity. Other researchers have similarly proposed that WM constraints are not caused by limits in the amount of WM activation but, instead, by how efficiently that capacity or activation is used (e.g., Case, Kurland, & Goldberg, 1982; Cowan, 1988; Daneman & Carpenter, 1980; Engle & Marshall, 1983; Shiffrin & Schneider, 1977). With more efficient memory use comes less strain and more capacity or activation for additional information to be processed or stored. However, researchers have not generally agreed, nor remained consistent, concerning the source or cause of memory efficiency.

We propose that more efficient WM task performance may result, at least partially, from better strategy use. However, it has generally been claimed that strategy use does not influence WM task performance (Engle et al., 1992; Engle et al., 1990; Just & Carpenter, 1992). This claim is based primarily on the assumption that the WM task occurs too quickly for the participant to use strategies, because the presentation rate is controlled by the experimenter. Moreover, an important assumption has been that the processing task prevents the use of coding and rehearsal strategies that are often employed for STM tasks, yielding a more pure measure of an individual's WM capacity (e.g., Engle et al., 1990). This assumption is bolstered by early findings that simple word and digit recall tasks do not correlate with verbal abilities (e.g., Perfetti & Goldman, 1976).

Although the absence of strategy use is critical to the validity of a WM measure, surprisingly little research has been conducted to directly examine the relationship of strategy use to WM performance. Engle et al. (1992), however, indirectly investigated strategy use as reflected by strategic allocation of resources from the processing task to the word-encoding task. They recorded viewing times across different portions of various span tasks and manipulated whether word recall was required. They found that resource allocation correlated with WM spans. High-span participants devoted more viewing time to the target words when recall was required than when recall was not required. This result indicated that participants strategically skimmed the processing tasks (i.e., sentences or mathematical operations) to devote more time processing the target words. However, when Engle et al. (1992) partialled out the effects of viewing times from the correlation between span scores and reading comprehension, the correlation increased (although nonsignificantly). Engle et al. (1992) also found that viewing time on various components of the processing task correlated significantly with SAT scores, but that viewing time on the target words did not. In contrast, viewing time on components of the processing task did not correlate with span, but viewing time on the target words did. Thus, processing and storage times were differentially related to span scores and SAT, so that neither index could account for the relationship between span and SAT. From these results, they concluded that strategy use was not a contributing factor to the correlation between reading comprehension and WM performance.

One important consideration is whether resource allocation as reflected by viewing time (by itself) adequately reveals the cognitive processes corresponding to strategy use. Specifically, Engle et al. (1992) did not directly examine participants' strategies. Moreover, researchers have relied on the assumption that strategies require more time. On the other hand, an important claim made by Ericsson and Kintsch (1995) was that mnemonic strategies render encoding and LTM access more, not less, efficient. Thus, if a participant were to use strategies to encode the words and did so effectively, the processes might not be revealed by viewing times.

EXPERIMENT 1

We hypothesized that if strategies influence WM capacity, strategy training on an STM task should increase WM spans. It is well established that mnemonic strategies improve STM task performance (e.g., Bower, 1970; Ross & Lawrence, 1968). Therefore, we provided participants with training (four sessions including 22 word lists) to use a STM strategy called *chaining* (e.g., Bower & Clark, 1969; Wright et al., 1990). Chaining is the process of creating associations between words in a list by making up a story with the words. For example, Bower and Clark found that participants using the chaining strategy recalled 93%, whereas yoked controls recalled only 13% of the target words during delayed recall. One purpose of Experiment 1 was to examine whether training participants to use this strategy would improve STM task performance. A second question was whether an observed improvement on the STM task after training would generalize to the WM task. If WM task performance is, at least partially, a function of word-encoding strategy use, strategy training should increase participants' WM spans. On the other hand, if WM span tasks are not affected by strategy use, STM strategy training should not affect WM task performance.

Method

Participants

Twenty-one students at Old Dominion University participated as a requirement or for extra credit in a psychology course. There were 7 males and 14 females, ranging from 17 to 45 years old, with an average age of 28 years.

Procedure and Materials

General procedure. Each participant attended five individual sessions that were completed within a 2-week time frame and required between 30 and 60 min for each session. The experimental tasks took place in the following order. Session 1 included (1) the WM pretest, (2) the STM pretest, (3) two training blocks consisting of 10 words each, and (4) two training blocks consisting of 15 words each. Sessions 2–4 each consisted of training with six lists containing 15 words each. Session 5 consisted of (1) the WM posttest and (2) the STM posttest. Across all lists, no target words were repeated.

Working memory task. The WM task requires the participant to read a set of sentences, each followed by an unrelated word, and then recall serially as many of the unrelated words as possible (see, e.g., Turner & Engle, 1989). The number of sentences and words in each set increased from two to six in a fixed pattern according to a Latin-square design. There were 18 total sets, with the first 3 sets of two sentences and words presented as practice trials and the remaining 15 sets making up the test. The experimenter controlled presentation rate by pressing the space bar after each sentence and word were read aloud. The task also included 22 simple comprehension questions presented randomly after serial recall of the words. It is notable that this comprehension measure also involves memory, in contrast to the sentence verification task used by Daneman and Carpenter (1980). Different sentences and unrelated words were used to create parallel (counterbalanced) forms for the pretest and posttest in such a way that no sentence or unrelated word appeared on both versions of the test.

Short-term memory task. The participant read aloud 15 words, each presented individually on a computer monitor, followed by the word RECALL to cue serial recall. The experimenter controlled presentation rate by pressing the space bar after each word was read aloud. Thus, the time spent on each word was affected by an individual's reading rate. Pretest and posttest word lists contained different words, and the lists were counterbalanced across testing sessions.

Short-term memory training. STM tasks during training were administered as during the pretest and posttest. As was described earlier, training included 22 word lists distributed across four sessions. The participants were advised to create simple stories with interrelated sentences and to ignore syntactic and semantic correctness. They received feedback focusing on how well word order in the story matched the correct order, how cohesively linked their stories were, how quickly they formed the stories, and the appropriateness of story length. In Sessions 1 and 2, the participants controlled word-presentation rate and were required to create their stories aloud. To accelerate task completion in Sessions 3 and 4, the experimenter controlled presentation rate, and the stories were created silently. Using a stopwatch, the experimenter allowed approximately 4 sec per word (after being pronounced) in Session 3, and 2 sec in Session 4. The participants recited their story after word recall.

Results

Short-Term Memory

STM test performance was analyzed in terms of the proportion of words recalled in the correct order (i.e., STM recall) and in terms of the number of words recalled per second of study (i.e., STM efficiency). To calculate STM efficiency, reaction time for the first word in each list was not included, because there were large variations among participants and because several participants asked the experimenter a question after the first word appeared on the screen, which distorted the first-word reaction times.

The correlations for pretest and posttest STM efficiency were .92 ($p < .001$) and .83 ($p < .001$) with STM pretest and posttest recall, respectively. As is shown in Table 1, STM recall improved reliably from the pretest to the posttest following training [$F(1,20) = 33.64$, $MS_e = 0.014$, $p < .001$]. STM efficiency also improved reliably [$F(1,20) = 14.98$, $MS_e = 0.004$, $p < .001$]. Thus, there was a reliable improvement in STM performance as a function of training.

Working Memory

WM span was calculated by summing perfect trials in which the participant recalled *all* of the words in correct order from that set. Other scoring methods (e.g., summing any words recalled in the correct order from all sets) led to the same conclusions and thus are not reported here. As is shown in Table 1, WM word recall reliably improved from pretest to posttest [$F(1,20) = 11.56$, $MS_e = 30.195$, $p = .003$]. WM efficiency was calculated by dividing the number of correctly recalled words by the response time to read the sentences and words. The correlations for pretest and posttest WM efficiency were .93 ($p < .001$) and .95 ($p < .001$) with WM pretest and posttest recall, respectively. WM efficiency also improved from pretest to posttest [$F(1,20) = 8.07$, $MS_e = 0.0002$, $p = .010$]. This result indicates that the participants' improvement was not at the expense of increasing the time to encode the sentences and words.

The number of comprehension questions answered correctly also improved from pretest to posttest [$F(1,20) = 8.58$, $MS_e = 0.748$, $p = .008$; see Table 1]. This result indicates that the increase in words recalled was not at the

Table 1
Descriptive Statistics for Working Memory (WM) Pretest and Posttest and Short-Term Memory (STM) Pretest and Posttest in Experiment 1

	Pretest		Posttest	
Measure	*M*	*SD*	*M*	*SD*
STM proportional word recall	0.33	0.12	0.54	0.18
STM efficiency	0.17	0.09	0.25	0.10
WM word recall	14.0	6.6	19.8	9.5
WM efficiency	0.04	0.02	0.05	0.03
WM sentence comprehension	14.9	2.9	17.1	3.2

expense of sentence comprehension and thus was not simply due to a reallocation of resources.

EXPERIMENT 2

Experiment 1 demonstrated that both STM task performance and WM task performance improved after strategy training, indicating that the word-chaining strategy used for the STM task successfully transferred to performance on the WM task. The purpose of Experiment 2 was to further examine whether improvement on the WM posttest was a function of strategy training or, alternatively, a function of practice after having performed the WM pretest. To examine this possibility, a control group was included who performed all of the training trials, but without strategy instructions. A second purpose of Experiment 2 was to examine the role of natural strategy use by assessing strategy use on the STM task before training. We also obtained SAT scores from participants to examine whether strategic participants had better verbal skills than did less strategic participants.

We predicted that the participants in the training group would improve from pretest to posttest in both the STM and the WM tasks. Second, we hypothesized that natural strategy use would improve word recall. Third, we hypothesized that the participants in the training condition would improve more from pretest to posttest than the participants in the control condition and would show better performance on posttest measures, particularly on the WM task. Finally, we predicted that strategic participants would have better verbal skills than would less strategic participants. This result would support our hypothesis that the relationship between verbal abilities and WM capacity is partially a function of whether the individual tends to use strategies, regardless of the task.

Method

Participants

Sixty students at Old Dominion University participated as a requirement or for extra credit in a psychology course. There were 20 males and 40 females ranging from 17 to 48 years old, with an average age of 23 years. On the basis of strategy use during the STM pretest, the participants were categorized as less strategic or strategic. Those participants who reported using rehearsal or "doing nothing" to remember the words were categorized as less strategic, whereas the participants who reported using semantically based strategies (e.g., creating mental images, creating stories, relating words to personal experience) were classified as strategic. Half of the participants in each group were assigned to each experimental condition (i.e., training or control), resulting in 10 strategic participants and 20 less strategic participants in each condition. There were no significant differences between the two experimental conditions on pretest measures.

Procedure

The participants in the training condition were tested and trained as described in Experiment 1, with two modifications. First, all of the participants were asked how they had attempted to remember the unrelated words after completing the STM and WM pretests and posttests. Second, STM training instructions were modified to include an example of chaining. Specifically, the participants were provided the sentence "My foot was stepped on by a cow who wore a shirt and lived in a hut with a stop sign that had no goals," corresponding to the words foot, cow, shirt, hut, sign, and goal.

The participants in the control condition attended the same number of sessions and were presented the same word lists as those in the training condition but were not provided with any strategy instructions. Control participants were asked to "think out loud" when presented word lists in the first two sessions, and to "think to themselves" in Sessions 3 and 4.

Results

Short-Term Memory

STM performance was analyzed in terms of STM recall and efficiency. However, STM efficiency yielded similar results and conclusions and thus are not reported here.

Short-term memory proportion of recall. A 2 $\times$ 2 $\times$ 2 mixed analysis of variance (ANOVA) was conducted, including the between-subjects variables of condition (training or control) and natural strategy use (strategic or less strategic) and the within-subjects variable of test (pretest and posttest). Training participants (M = 0.470, SD = 0.095) recalled more words than did control participants [M = 0.418, SD = 0.106; $F(1,56) = 4.82$, $MS_e = 0.015$, $p = .032$], and strategic participants (M = 0.502, SD = 0.096) recalled more words than did less strategic participants [M = 0.387, SD = 0.084; $F(1,56) = 23.86$, $MS_e = 0.015$, $p < .001$]. Condition and strategy use did not interact ($F < 1$).

Improvement from pretest (M = 0.357, SD = 0.093) to posttest (M = 0.493, SD = 0.152) was reliable [$F(1,56) = 67.92$, $MS_e = 0.009$, $p < .001$]. Most important, the predicted interaction between test and condition was reliable [$F(1,56) = 6.25$, $MS_e = 0.009$, $p = .015$]. Pretest recall was equivalent for control (M = 0.358, SD = 0.100) and training (M = 0.356, SD = 0.086) participants. In contrast, posttest recall was greater for training participants (M = 0.544, SD = 0.140) than for control participants [M = 0.442, SD = 0.148; $F(1,58) = 7.56$, $MS_e = 0.021$, $p = .008$]. Nevertheless, it is notable that recall reliably improved from pretest to posttest for both control participants [$F(1,28) = 17.48$, $MS_e = 0.008$, $p < .001$] and training participants [$F(1,28) = 54.56$, $MS_e = 0.009$, $p < .001$]. Hence, practice also led to some improvement.

There was also a marginal interaction between test and participants' classification of natural strategy use [$F(1,56) = 3.78$, $MS_e = 0.009$, $p = .057$]. Separate analyses indicated that the benefit of natural strategy use was reliable on both the pretest [$F(1,56) = 11.65$, $MS_e = 0.0073$, $p = .001$; strategic M = 0.410, less strategic M = 0.330] and the posttest [$F(1,56) = 18.64$, $MS_e = 0.0161$, $p < .001$; strategic M = 0.593, less strategic M = 0.443]. In addition, improved STM recall from pretest to posttest was observed for both less strategic participants [$F(1,38) = 54.64$, $MS_e = 0.005$, $p < .001$] and strategic participants [$F(1,18) = 19.83$, $MS_e = 0.017$, $p < .001$]. Hence, the source of this two-way interaction is unclear. The three-way interaction among condition, strategy use classification, and test was not reliable [$F(1,56) = 1.45$, $MS_e = 0.009$, $p = .234$].

Short-term memory posttest strategy use. All but 1 of the 30 training participants reported using the chaining strategy on the STM posttest. This participant reported using rehearsal on the posttest and had used no strategy on the pretest. In contrast, 17 of the 30 participants in the control condition did not use a semantic strategy on the posttest, but reported using rehearsal or no strategy. As can be expected, those who reported using a semantic strategy for the posttest recalled more words ($M = 0.548$, $SD = 0.142$) than did those who did not [$M = 0.367$, $SD = 0.083$; $F(1,58) = 25.21$, $MS_e = 0.016$, $p < .001$].

Working Memory

WM was analyzed in terms of (1) the number of words recalled by summing perfect trials, (2) the number of sentence comprehension questions answered correctly, and (3) participants' strategy use. For each measure, a 2 × 2 × 2 mixed ANOVA was conducted, including the between-subjects variables of condition (training or control) and natural strategy use (strategic or less strategic) and the within-subjects variable of test (pretest and posttest). WM efficiency scores yielded the same results as WM word recall and thus are not reported here.

Working memory word recall. There was a main effect of condition [$F(1,56) = 6.96$, $MS_e = 58.296$, $p = .011$], reflecting better recall by training participants ($M = 19.3$, $SD = 6.1$), as compared with control participants ($M = 15.4$, $SD = 6.0$). There was also a main effect for natural strategy use [$F(1,56) = 15.26$, $MS_e = 58.296$, $p < .001$], reflecting higher recall by strategic participants ($M = 20.2$, $SD = 5.6$), as compared with less strategic participants ($M = 14.5$, $SD = 6.0$). These factors did not interact [$F(1,56) = 2.32$, $MS_e = 58.296$, $p = .134$].

As is shown in Table 2, improvement from pretest to posttest was reliable [$F(1,56) = 29.80$, $MS_e = 16.354$, $p < .001$], as was the interaction between improvement and condition [$F(1,56) = 22.32$, $MS_e = 16.354$, $p < .001$]. As was predicted, the control participants did not significantly improve ($F < 1$), whereas the participants in the training condition showed a large improvement following strategy training [$F(1,28) = 51.20$, $MS_e = 16.562$, $p < .001$].

Improvement on test did not interact with strategy use ($F < 1$). Also, the three-way interaction was not significant ($F < 1$). These results remained unchanged when either response time or sentence comprehension accuracy was included as a covariate. The absence of an interaction reflects a reliable effect of natural strategy use on both the pretest [$F(1,56) = 15.15$, $MS_e = 30.63$, $p < .001$] and the posttest [$F(1,56) = 9.67$, $MS_e = 44.02$, $p = .003$]. In addition, the lack of an interaction indicates a benefit of training for strategic participants. Although strategic participants had used effective strategies prior to training, there apparently remained room for improvement.

Working memory comprehension questions. The main effects of condition and strategy use classification and their interaction were not reliable (all Fs < 1). There was a main effect of test [$F(1,56) = 8.63$, $MS_e = 4.450$, $p = .005$], reflecting better posttest ($M = 17.067$, $SD = 2.629$) than pretest ($M = 15.900$, $SD = 2.735$) performance. However, improvement did not reliably depend on condition or strategy use classification, nor was there a three-way interaction (all Fs < 1).

Working memory strategy use. After completing each of the WM tests (i.e., pretest and posttest), the participants were asked how they had tried to remember the words, to determine whether they used any strategy during the two WM tests and whether their strategy changed from pretest to posttest. Strategies were rated on a 4-point scale: 0 = *no strategy used*; 1 = *rehearsal*; 2 = *combination of rehearsal along with other, more semantic forms of processing*; 3 = *semantic processing that consisted of relating words to self, making up stories with the words, relating the words to the sentences, and imagery formation.* There were no differences between condition on the pretest: 5 participants reported using no strategy, 17 reported using rehearsal, 20 reported using combined strategies, and 18 reported using a semantic strategy. This distribution of strategy use on the pretest indicates that there was a tendency for the participants to use some type of strategy to remember words on the WM task. On the posttest, the distribution of strategy use remained unchanged for the control group: 3 reported using no strategy, 10 used rehearsal, 8 used a combination, and 9 used a semantic strategy. In contrast, none of the training participants reported using no strategy, 1 used rehearsal, 8 used a combination, and 21 used a semantic strategy (i.e., the chaining strategy).

A mixed ANOVA was conducted on strategy use scores (see Table 2). There was a main effect of condition [$F(1,56) = 7.60$, $MS_e = 0.878$, $p = .008$], reflecting better overall strategy use by training participants ($M = 2.413$, $SD = 0.549$), as compared with control participants ($M = 1.913$, $SD = 0.917$). Not surprisingly, naturally strategic participants ($M = 2.550$, $SD = 0.583$) showed better overall strategy use on the WM task than did less strategic participants [$M = 1.775$, $SD = 0.776$; $F(1,56) = 18.25$, $MS_e = 0.878$, $p < .001$]. However, con-

Table 2
Descriptive Statistics for Working Memory (WM) Pretest and Posttest Word Recall and Strategy Use Scores as a Function of Condition and Natural Strategy Use in Experiment 2

	WM Word Recall				WM Strategy Use Scores			
	Pretest		Posttest		Pretest		Posttest	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control								
Less Strategic	10.7	4.4	12.1	6.2	1.40	0.99	1.45	0.94
Strategic	19.5	5.9	19.3	5.6	2.40	0.70	2.40	0.84
Total	13.6	6.4	14.5	6.8	1.73	1.01	1.77	1.01
Trained								
Less Strategic	13.8	5.5	21.3	7.4	1.70	0.80	2.55	0.60
Strategic	16.8	7.0	25.3	6.8	2.50	0.85	2.90	0.32
Total	14.8	6.1	22.6	7.3	1.97	0.89	2.67	0.55
Total								
Less Strategic	12.3	5.2	16.7	8.2	1.55	0.90	2.00	0.96
Strategic	18.2	6.5	22.3	6.8	2.45	0.76	2.65	0.67
Total	14.2	6.3	18.5	8.1	1.85	0.95	2.22	0.92

dition and strategy use classification did not interact [$F(1,56) = 1.22$, $MS_e = 0.878$, $p = .275$].

As is shown in Table 2, there was a main effect of test [$F(1,56) = 6.59$, $MS_e = 0.428$, $p = .013$], reflecting a higher quality of strategy use during the WM posttest than during the pretest. However, improvement across tests depended on condition [$F(1,56) = 5.61$, $MS_e = 0.428$, $p = .021$]. Control participants made no improvement in strategy use, whereas training participants significantly increased the quality of strategy use from pretest to posttest [$F(1,28) = 10.82$, $MS_e = 0.481$, $p < .001$]. Improvement did not depend on natural strategy use, and the three-way interaction of condition, test, and STM strategy classification was not significant (both Fs < 1).

In turn, the question can be asked as to whether the type of strategy used by a participant directly impacted performance on the WM posttest. To answer this question, an analysis was conducted on WM posttest recall, including the between-subjects variable of strategy type. The 3 participants who used no strategy on the posttest were grouped together with 11 participants who reported using rehearsal. Thus, there were three groups: those who reported using no strategy or rehearsal (i.e., *rehearsal*; $n = 14$), those who reported rehearsal and semantic strategies (i.e., *mixed*; $n = 16$), and those who consistently reported using semantic strategies (i.e., *semantic*; $n = 30$). There was a reliable effect of strategy type on WM word recall [$F(2,57) = 6.38$, $MS_e = 56.155$, $p = .003$]. According to post hoc Tukey HSD tests, this result reflects better recall for participants who used semantic strategies ($M = 21.033$, $SD = 8.402$) and mixed strategies ($M = 19.188$, $SD = 6.025$), as compared with those who used rehearsal alone ($M = 12.429$, $SD = 6.847$).

SAT Scores

We were able to obtain Verbal and Quantitative SAT scores for only 34 of the participants (VSAT, $M = 504$, $SD = 72$; QSAT, $M = 486$, $SD = 81$). In each condition, there were 4 participants who were strategic and 13 participants who were less strategic. A 2×2 multivariate ANOVA was conducted on the SAT scores, including the between-subjects variables of condition (training or control) and strategy use (strategic or less strategic). The main effect of condition was not reliable for either SAT score (both Fs < 2). There was a main effect of strategy use classification for VSAT scores [$F(1,30) = 6.65$, $MS_e = 4325.833$, $p = .015$], but not for QSAT scores ($F < 1$). The former result reflects higher VSAT scores for strategic participants ($M = 556$, $SD = 88$), as compared with less strategic participants ($M = 488$, $SD = 59$). The interaction of condition and strategy use was nonsignificant for both the VSAT and the QSAT scores (both Fs < 2).

For those with SAT scores, a comparison of the 10 low working memory span participants (WM recall < 10 words; VSAT, $M = 485$, $SD = 65$; QSAT, $M = 452$, $SD = 47$) to the 9 high-span participants (WM recall > 19; VSAT, $M = 558$, $SD = 75$; QSAT, $M = 537$, $SD = 69$) revealed significant effects of span for both the VSAT scores [$F(1,17) = 5.10$, $MS_e = 4917.974$, $p = .037$] and the QSAT scores [$F(1,17) = 10.03$, $MS_e = 3{,}385.882$, $p = .006$]. These results replicate previous findings for differences between high- and low-span individuals.

Discussion

Experiments 1 and 2 demonstrated that providing participants with training in the use of the chaining strategy on an STM task improves word recall on both the STM task and a WM task. Experiment 2 further showed that a control group without strategy instructions increased STM word recall but did not improve WM task performance as a function of practice. Thus, improvement on the WM task depended on training the participants to use a more effective strategy to encode the words. Experiment 2 also showed that only 5 of 60 participants reported using *no* strategies to complete the WM pretest, supporting our assumption that there is a tendency to use rehearsal or semantic strategies and indicating that WM task performance is not strategy free. Moreover, word recall was a function of strategy use: (1) more semantically based strategies led to superior word recall than did rehearsal alone, and (2) naturally strategic participants recalled more words than did less strategic participants. Although the latter result supports our predictions, it can also be explained in terms of a capacity account: That is, strategic individuals were able to use strategies *because* they had more capacity available. However, a capacity account cannot explain why less strategic individuals were able to learn strategies, which increased their WM span.

We have argued that strategy use on the WM task renders performance more efficient. In support of that argument, the results indicated that our conclusions are not compromised by strategic reallocation of resources. If the participants were merely reallocating their resources and skipping over the sentences to allot extra resources to the target words (see, e.g., Engle et al., 1992), sentence comprehension scores would have decreased after training. On the contrary, sentence comprehension during the WM task reliably improved from pretest to posttest. WM efficiency scores also improved, indicating that the participants were not merely spending more time on the words and sentences. Finally, the increase in WM recall remained unchanged when comprehension scores and response time were included as covariates. These results collectively indicate that the participants became more efficient as a function of training. Thus, more resources were available to complete both the processing and the storage tasks.

We also found in Experiment 2 that individuals with more effective memory strategies (before training) tended to have better verbal skills according to the VSAT. This finding suggests that strategy use may be a common factor to WM tasks and verbal ability tasks. If so, strategy use may contribute to the correlations between these tasks. However, these results emerged with a relatively small number of participants and thus are only preliminary. Clearly more research is needed that further investigates the relationship between verbal skills, reading strategies, and memory strategies before strong conclusions can be drawn.

As was mentioned earlier, little research has examined the relationship of strategy use to WM performance (cf. Engle et al., 1990). However, research has indicated that the relationship of WM capacity is more pronounced on reading tasks that require strategic processing. Daneman and Carpenter (1980) found extraordinarily high correlations (i.e., $R = .90$) between their reading span measure and pronominal inference questions. Later research confirmed that WM correlated with (1) inference generation within and between sentences in the passages (Cochran & Davis, 1987; Daneman & Carpenter, 1983); (2) inferences based on passage context concerning the meanings of new words (Daneman & Green, 1986); and (3) bridging and causal inference questions (Engle et al., 1991). Moreover, Whitney and colleagues (e.g., Budd et al., 1995; Whitney et al., 1991) have found that high-span individuals are more strategic readers. The types of strategies used by high-span individuals led to better text interpretation, as well as to better memory for details of the text.

Results indicating that high-capacity readers are more strategic readers have generally been interpreted in the context of a capacity-constrained account (c.f. Daneman & Carpenter, 1980). Accordingly, low-span individuals do not have sufficient WM capacity or resources to engage in the strategic processes or the capacity to retain in consciousness the separate sources of information necessary to generate inferences. However, if this interpretation were correct, it would follow that it would be futile to train less skilled readers to generate inferences or to engage in metacognitive reading strategies. In contradiction to the capacity account, numerous studies have demonstrated that teaching readers to generate inferences and to use metacognitive learning and reading strategies improves comprehension and learning skills (e.g., Cornoldi & Oakhill, 1996; Palincsar & Brown, 1984; Paris et al., 1984; Yuill & Oakhill, 1988). Moreover, there is recent evidence that strategy training not only improves comprehension and learning tasks administered in laboratory settings, but also improves college exam scores (McNamara & Scott, 1999). Thus, strategy use is generally learned at an early age (see, e.g., Baker, 1994; Moely et al., 1992) but can be trained through adulthood. A capacity theory cannot account for these reading intervention results. Hence, we propose that skilled and less skilled readers are forced into using particular strategies not solely by WM capacity limitations, but also by limited knowledge of strategies.

One important question concerns why some individuals use strategies, whereas others do not. Ericsson and Kintsch (1995) have suggested that strategy use is a result of practice and experience. However, expertise and the associated strategies are generally domain specific and do not tend to generalize to other domains (see, e.g., Ericsson & Chase, 1982). Hence, training strategies within a particular domain would not be expected to transfer to other domains. For example, our trainees would not be expected to become more strategic readers as a result of learning memory strategies. However, another important factor to strategy use, or metacognitive awareness, is whether the individual was taught or made aware of the benefits of strategy use at a young age (see, e.g., Baker, 1994, 1996; Freund, 1990; Moely et al., 1992). Baker (1996) emphasizes the role of parents and teachers for early learning of metacognitive strategies, or strategies that enhance performance across a wide variety of situations. Moely et al. found that children who were trained and encouraged to use strategies were more likely to use the strategies in the specified learning situations and were more likely to generalize these strategies to different situations in which they could be effectively used. On the other hand, children who were taught strategies and then left on their own to use them with no extra encouragement showed a slow decline in strategy use after training and seldom generalized the strategies they learned to other pertinent situations. These results suggest that whether an individual uses strategies at least partially depends on whether they were taught and encouraged to use strategies as children.

The conclusion drawn from the results presented here is that WM task performance is improved and rendered more efficient by strategy use. This conclusion is based on (1) improved WM task performance as a function of short-term strategy training, (2) superior WM task performance as a function of natural strategy use before training, particularly semantic strategies, and (3) the inability of strategic allocation from the processing to the storage task to account for the results, indicating that strategy use rendered storage more efficient. This conclusion is bolstered by studies demonstrating (1) the importance of strategy use and the effectiveness of strategy training for verbal ability tasks and (2) the pronounced relationship of WM capacity with reading tasks that require strategic processing. Moreover, we also found that individuals with more effective memory strategies (before training) tended to have better verbal skills according to the VSAT. Whether the correlation between these two types of tasks can be attributed to strategy use remains an open, although intriguing, question. Strategy use clearly merits greater attention in future studies of WM and verbal abilities.

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