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Working Memory Training May Increase Working Memory Capacity but Not Fluid Intelligence

Tyler L. Harrison[1], Zach Shipstead[2], Kenny L. Hicks[1], David Z. Hambrick[3], Thomas S. Redick[4], and Randall W. Engle[1]
[1]Georgia Institute of Technology; [2]Arizona State University; [3]Michigan State University; and [4]Purdue University

Abstract
Working memory is a critical element of complex cognition, particularly under conditions of distraction and interference. Measures of working memory capacity correlate positively with many measures of real-world cognition, including fluid intelligence. There have been numerous attempts to use training procedures to increase working memory capacity and thereby performance on the real-world tasks that rely on working memory capacity. In the study reported here, we demonstrated that training on complex working memory span tasks leads to improvement on similar tasks with different materials but that such training does not generalize to measures of fluid intelligence.

Keywords
attention, cognitive ability, intelligence

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Working memory is the interplay between attention and memory that regulates the maintenance and flow of information in the service of current goals. This system is important for keeping task goals (and information relevant to these goals) in an active mental state and for preventing attention from being captured by irrelevant events, either from the environment or from task-irrelevant thoughts. Working memory capacity (WMC) is important for a wide range of real-world cognitive tasks, including reading comprehension and problem solving, as well as for learning complex tasks and multitasking (Engle & Kane, 2004). In addition, environmental factors such as sleep deprivation and stereotype threat lead to a temporary reduction in WMC (Ilkowska & Engle, 2010). It has also been argued that WMC plays an important causal role in fluid intelligence (Gf)—the ability to reason and solve problems in novel contexts—because these variables correlate quite highly at the latent-construct level (*r*s = .6–.7; Kane et al., 2004).

Assuming that WMC limitations place constraints on the performance of complex cognition, it stands to reason that training-related improvements on working memory tasks may improve complex cognition. Numerous studies have explored this possibility (e.g., Chein & Morrison, 2010; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg et al., 2005). For example, in a set of experiments, Jaeggi and her colleagues trained subjects for multiple days on a dual *n*-back task, in which the goal on each trial was to indicate whether the current item was identical to the one presented *n* trials back. One problem in interpreting the extensive literature showing the validity of the WMC is that these studies largely used complex span tasks, whereas most training studies use tasks such as *n*-back or simple span tasks. Thus, any effects of training on tasks such as the *n*-back may not reflect the same construct as the effects of training on complex span tasks. One example of a complex span task is the operation-span task, in which subjects alternately solve simple arithmetic problems and see letters.

Corresponding Author:
Randall W. Engle, School of Psychology, Georgia Institute of Technology, 654 Cherry St., Atlanta, GA 30332
E-mail: randall.engle@gatech.edu

After some number of these interleaved items, subjects attempt to recall the letters in the order in which they occurred (Engle & Kane, 2004). A battery of such tasks is used to develop a measure of WMC at the construct level. There is good evidence that some tasks thought to measure WMC (e.g., complex span and *n*-back tasks) do not measure the same construct. For example, researchers have found that performance on the operation-span task correlated weakly with performance on the *n*-back task (Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Kane, Conway, Miura, & Colflesh, 2007).

Transfer occurs when practicing one task has an effect on performance on another task. (Barnett & Ceci, 2002). The transfer is said to be *near* if the two tasks have formal similarity or *far* if the surface and structural features of the tasks appear to be different. For many studies in the cognitive-training literature, the goal has been to show far transfer (e.g., to Gf; Shipstead, Redick, & Engle, 2010, 2012). However, from a theoretical perspective, a logical requirement for a claim of far transfer is the demonstration of near transfer. For example, arguing that working memory training improves Gf because of the relationship between the two constructs would not make sense if working memory is not improved at the construct level. Few studies in this literature have followed this necessary logical trail, and no study has unambiguously answered the question of whether WMC can be improved by working memory training (Shipstead, Hicks, & Engle, 2012).

Furthermore, it is possible that working memory training can improve performance on WMC tasks without improving WMC at the construct level. In factor-analytic studies, the loading of operation span on a WMC factor is typically around .80 (Kane et al., 2004). This means that around 64% of the variance in operation span reflects WMC (i.e., $.80^2 \times 100 = 64\%$) but that 36% of the variance reflects one or more other factors, such as strategies, the ability to chunk letters, random error, etc. Therefore, researchers must be cautious when interpreting improvements on one specific task, because the improvements could be attributed to some variable other than the variable of interest. Consequently, WMC at the construct level can be shown to be improved only if multiple measures of WMC show improvements from training and if these measures do not share many incidental features with the training tasks (e.g., both the training task and the transfer measure require memory for letters).

The Present Study

The purpose of the research reported here was to determine whether working memory training improves WMC, and if so, whether such improvements transfer to measures of fluid intelligence. We included a simple-span-training condition to compare the results of our study with those of other studies that used simple-span-training tasks (Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002). Critically, both the complex-span and simple-span groups were compared with a control group (i.e., the visual-search-training condition) that was active and adaptive. The visual-search-training condition was used as a control because visual search has been shown to be unrelated to WMC (Kane, Poole, Tuholski, & Engle, 2006), and using an active and adaptive task controls for motivational effects (Shipstead, Redick, & Engle, 2012). We examined whether WMC was improved by assessing performance on tasks similar to our training tasks but that required memory for different stimuli and on tasks dissimilar from our training tasks but that required memory for the same stimuli (both of which would indicate near transfer). We also assessed transfer effects to tasks dissimilar to our training tasks but that were theorized to reflect WMC (which would indicate moderate transfer). Far transfer would be demonstrated if training on complex span tasks led to improvement on a battery of Gf tasks.

Method

Subjects and design

Subjects were 87 undergraduate students at either Georgia Institute of Technology (n = 31) or Georgia State University (n = 56) and were randomly assigned to three conditions (complex-span training, simple-span training, or visual search training). Thirty-two subjects dropped out of the study, which left 55 subjects who completed all sessions (21 in the complex-span condition, 17 in the simple-span condition, 17 in the visual search condition). Subject attrition was not related to condition, $\chi^2(2, N = 87) = 2.49, p = .288$. All subjects completed a pretest on a battery of near-, moderate-, and far-transfer tasks, followed by 20 sessions of training lasting approximately 45 min each, and finally a posttest. The posttest tasks were the same as those presented at pretest, except that different stimuli or questions were used. The two versions of the tasks were counterbalanced across subjects. All subjects were paid $40 for each assessment session (pretest and posttest), and $10 per training session. Subjects could also earn up to $12 per training session by obtaining high levels of performance on the tasks. This increased the chance that subjects were highly motivated to perform the training tasks over the 20 sessions.

Procedure for training sessions

Complex-span training. Subjects in the complex-span-training condition completed adaptive versions of both the operation-span and symmetry-span tasks for each session of training.

Adaptive operation-span task. For the adaptive operation-span task, subjects had to remember individually presented letters in correct serial order and solve math equations between letter presentations (see Fig. 1a). Subjects first saw an equation. When they solved it, they clicked the mouse and a number appeared. The subject then indicated whether this number was the solution for the equation. On the following screen, subjects saw a letter. After a certain number of equations alternating with letter presentations, a recall screen appeared, and subjects had to select the letters in the order in which they had been displayed.

For every session, subjects had to perform eight sets of operation-span trials. Each set consisted of three trials and was associated with a level of difficulty. The level of difficulty was determined by the set size, that is, the number of equations and letters to be remembered. After subjects completed a set of trials, a feedback screen displayed the percentage of correctly solved equations and correctly recalled letters. If subjects correctly solved 87.5% or more of the equations and remembered 87.5% or more of the letters, they proceeded to the next difficulty level. If subjects correctly answered fewer than 75% of the equations or remembered fewer than 75% of the letters, the

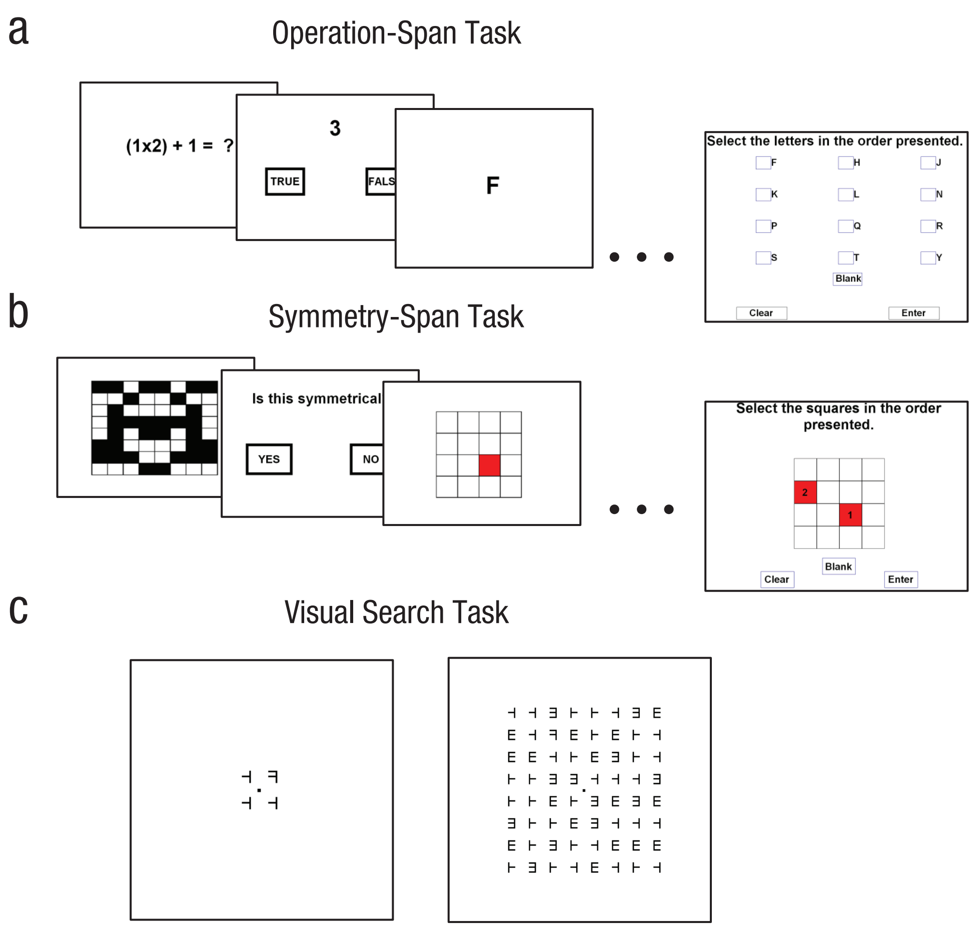

Fig. 1. Example trial sequences from (a, b) the two tasks used in the complex-span training sessions and from (c) one task used in the simple-span training sessions. In the adaptive operation-span task, subjects saw a math problem and then had to indicate whether a presented answer was correct. These problems and answers alternated with single letters. At the end of each set of trials, subjects had to recall the letters in the order in which they had been presented. In the adaptive symmetry-span task, subjects saw a matrix consisting of black and white squares and then had to answer whether the pattern of squares was symmetrical on its vertical axis. This matrix alternated with a different matrix, in which one square was highlighted in red and the rest were unfilled. At the end of each set of trials, subjects had to indicate the order in which the highlighted squares in the second matrix had been displayed. In the adaptive visual search task, subjects saw an array consisting of one target (an "F" or a mirror-reversed "F") and a variable number of distractors. The left panel shows an example of an array from an easy level (Level 1), in which the array size was 2 × 2 and all the distractors were homogeneous. The right panel shows an example from a more difficult level (Level 8), in which the array size was 8 × 8 and the distractors were heterogeneous. On each trial, subjects had to indicate which direction the target was facing.

difficulty level of the next set of trials decreased by one. Each successive difficulty level included one more equation and one more letter on each trial. Level 1 difficulty contained three trials with set sizes 2, 3, and 4, so Level 12 contained three trials with the set sizes 13, 14, and 15.

At the end of the eighth set, a screen was displayed that showed the next level the subject would perform. Subjects started each session on the level that they ended on their previous session. The level that subjects ended on also determined the amount of bonus compensation that they earned on that session.

Adaptive symmetry-span task. For the adaptive symmetry-span task, subjects had to remember matrix locations in correct serial order and make symmetry judgments between matrix location presentations (see Fig. 1b). Subjects first saw a large array of white and black squares and were asked to determine whether the array was symmetric about its vertical axis. After subjects made their symmetry judgments, they saw a position on a different 4 × 4 matrix highlighted in red. After a certain number of symmetry judgments alternating with matrix location presentations, a recall screen appeared, and subjects had to click the locations of the highlighted positions in the order in which they had been displayed.

The level-progression criteria, number of sets, number of trials per set, and bonus compensation per level were identical to those in the adaptive operation-span task. The number of symmetry judgments and matrix positions were exactly the same per level as those for the adaptive operation-span task.

Simple-span training. Subjects in the simple-span-training condition completed two adaptive simple span tasks. These two tasks were identical to the training tasks used in the complex-span-training condition, except that there was no interfering task between to-be-remembered item presentations.

Adaptive letter-span task. The adaptive letter-span task was closely related to the adaptive operation-span task in that subjects had to recall letters in their correct serial positions. Letters were presented one at a time. Afterward, subjects selected the letters they had seen in sequential order. Subjects performed eight sets of three trials, and each set was associated with a level of difficulty. The number of letters that subjects had to remember in a given trial was the same as for the adaptive complex span tasks. If subjects recalled 87.5% or more of the letters in correct serial order, they progressed to the next level. If subjects recalled 75% or fewer of the letters in correct serial order, they regressed a level. Otherwise, the subject stayed on the same level. The bonus compensation rate was the same as that in the adaptive complex span tasks.

Adaptive matrix-span task. The adaptive matrix-span task was similar to the adaptive symmetry-span task. Subjects saw a number of matrix locations highlighted one by one and were then shown a recall screen, on which they selected the correct matrix locations in sequential order. Subjects completed eight sets of three trials for every session of training.

Adaptive visual search task. Subjects in the adaptive visual search control condition were trained on only one task. For this task, subjects saw a brief array of letters in which there was one "F" (Redick et al., 2013; see Fig. 1c). The "F" was either facing toward the right (as it normally does) or to the left (a mirror-reversed "F"). Subjects had to indicate which direction the target was facing on each trial. The distractors were "E," mirror-reversed "E," and inverted "T." On each trial, subjects saw a fixation dot in the center of the screen, and then the array of letters was presented for 500 ms. The size of the array depended on the level of difficulty for the block of trials; it ranged from a 2 × 2 array (1 target and 3 distractors) to a 16 × 16 array (1 target and 255 distractors). After the array was presented, there was a mask that consisted of a 16 × 16 array of black squares and lasted 2,500 ms. Subjects made their responses during the mask presentation.

Each block consisted of 24 trials. There was a total of 16 blocks per experimental session. Each block was associated with a level of difficulty. If subjects responded accurately on 87.5% or more of the trials in a block, the difficulty level of their next block of trials increased. If subjects were less than 75% accurate in a block, the level of their next block of trials decreased. Otherwise, the difficulty of their next block of trials stayed the same. On odd-numbered levels, the distractors were homogeneous; on even-numbered levels, the distractors were heterogeneous. On each level, the array size increased (e.g., from a 3 × 3 array to a 4 × 4 array). Subjects earned bonus compensation based on the final level they attained at the ended of each session. Subjects earned double what subjects in the span training conditions made per level, because subjects in the visual-search-training group only performed one training task.

Procedure for pre- and posttest assessments

Subjects completed a battery of tasks for both the pre- and posttest assessment sessions. Only the tasks relevant to the present article[1] are presented here (Barnett & Ceci, 2002).

Near-transfer tasks. There were six measures of near transfer.

Reading-span task. For the reading-span task, subjects first saw a sentence and had to judge whether the sentence made sense (see Fig. 2). After the sentence judgment, subjects were shown a four-letter word to remember. A certain number of sentence judgments and words alternated on each trial until a recall screen appeared. Subject had to click the words on the recall screen in the order in which they had been presented. The number of words per trial ranged from 3 to 10, and there were a total of 15 trials.

Rotation-span task. For the rotation-span task, subjects saw a letter rotated to one of eight different angles (see Fig. 2). Subjects had to indicate whether the letter when in the upright position was facing the correct direction or was mirror-reversed. After the rotation judgment, subjects saw a short or long arrow pointing in one of eight directions. After a certain number of rotation judgments and arrow presentations, a recall screen appeared. Subjects had to click on the arrows on the recall screen in the order in which they had seen them. Between 3 and 10 arrows were presented on each trial, and there were a total of 15 trials.

Word-span task. The word-span task was identical to the reading-span task, except that subjects saw only the to-be-remembered words. On the recall screen, subjects had to click the words in the order in which they had appeared.

Arrow-span task. The arrow-span task was identical to the rotation-span task, except that subjects did not see the rotated letters. On the recall screen, subjects had to recall the arrows in the order in which they had appeared.

Running-letter-span task. In the running-letter-span task, subjects saw a series of letters presented one at a time (at a rate of two letters per second). Once a recall

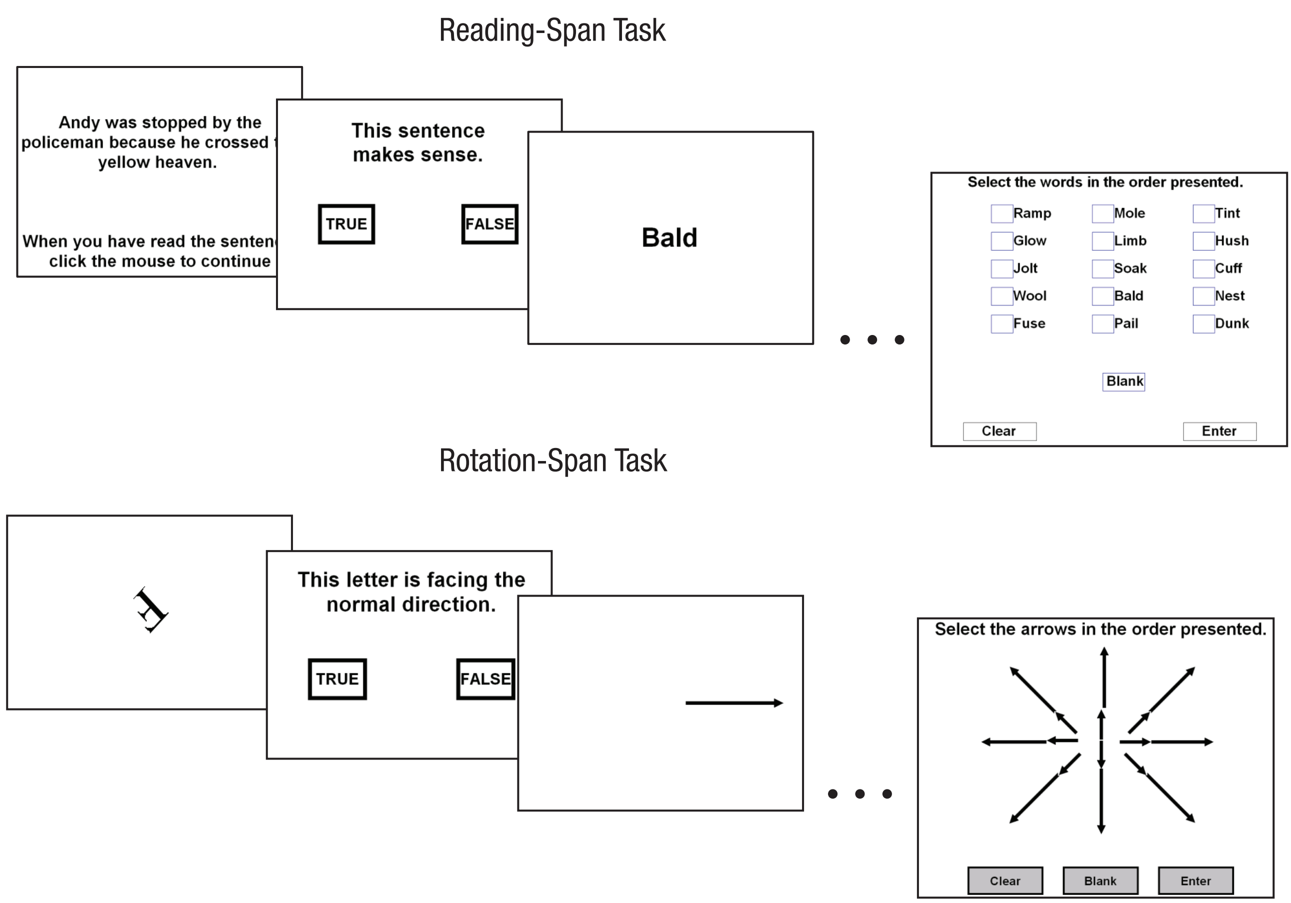

Fig. 2. Example trial sequences from two of the near-transfer tasks. On the reading-span task, subjects were shown a sentence and then asked to judge whether the sentence made sense. Sentence judgments alternated with the presentation of four-letter words. At the end of each set of trials, subjects had to indicate the order in which the words had been presented. On the rotation-span task, subjects were shown a letter rotated to one of eight different angles and then asked to indicate whether the letter was facing in the normal direction. Rotation judgments alternated with the presentation of arrows pointing in one of eight directions. At the end of each set of trials, subjects had to indicate the order in which the arrows had been presented.

screen appeared, subjects had to recall the most recent *n* number of items (e.g., the last six letters) in serial order. Before each trial, subjects were told the number of letters (set size) that they should remember. This number ranged from 3 to 9. Subjects completed two trials per set size for a total of 14 trials.

Running-spatial-span task. The running-spatial-span task was identical to the running-letter-span task, except that matrix locations on a 4 × 4 matrix were the to-be-remembered stimuli.

Moderate-transfer tasks. There were four measures of moderate transfer.

Keep-track task. For the keep-track task, subjects were shown 16 words, sequentially, from up to six categories and were told to remember the most recent instances of a certain number of categories. For example, if the subject was told to remember the most recent country and was then presented with a list ending with France, Mile, Zinc, Russia, and Yellow, the subject should select "Russia" at the end of the list. There were 15 trials in total, and the number of categories per trial from which to-be-remembered words were drawn from (set size) was 2, 3, 4, 5, or 6. Before each trial, subjects were told the categories that they should identify and recall the most recent instances from. Once the words were presented, subjects were then shown the six instances of a category.

Visual-arrays task. In the visual-arrays task, subjects saw an array of colored squares for 500 ms. After a short delay, another array appeared in which either all squares were identical to those in the previous array or one of the squares was a different color. Subjects indicated whether the second array was identical to the first. Arrays consisted of four, six, or eight squares. The dependent variable of interest was a Cowan's *k* (cf. Cowan et al., 2005).

Immediate free-recall task. For the immediate free-recall task, subjects saw five lists of 10 words each. Each word was presented sequentially. They had to type as many of the words as they could recall in any order after seeing each list. All the words were four letters long and contained only one syllable. Two dependent measures were obtained from this task, a measure of primary memory and a measure of secondary memory. We used the Tulving and Colotla (1970) procedure to calculate these scores.

Far-transfer tasks. There were three measures of far transfer.

Raven's Advanced Progressive Matrices task (Raven, Raven, & Court, 1998). On this task, subjects saw a 3 × 3 matrix of figures. The lower right part of the matrix was missing, but there was a certain logical pattern for each matrix. Subjects had to select a figure from one of eight choices to complete the matrix in a way that was consistent with the pattern. Subjects had 10 min to complete 18 problems.

Letter-sets task (Ekstrom, French, Harman, & Dermen, 1976). On this task, subjects saw five sets of four letters. Four of the sets followed a certain pattern. Subjects had to select the letter set that did not follow the pattern. Subjects had 7 min to complete 15 problems.

Number-series task (Thurstone, 1938). In this task, subjects saw a series of numbers arranged in a certain pattern and were asked to select the next number that would be consistent with the pattern out of five choices. Subjects had 5 min to complete 10 problems.

Results and Discussion

All statistical analyses were conducted with an alpha level of .05. Unless otherwise noted, all analyses were conducted on the 55 subjects who completed the study.

Progress on training tasks

To determine how much performance improved in each task, we first calculated the average difficulty level that subjects achieved for each training session. To put the scores on the same scale, we converted them to standard-deviation units and then subtracted the average performance from the first training session. This yielded standardized improvement scores relative to the first session of training (see Fig. 3). Regardless of condition, subjects improved approximately 2.5 standard deviation units over the course of training.

Transfer of training

For each of the assessment tasks, we conducted an analysis of covariance (ANCOVA) with group as the between-subjects variable and subjects' pretest performance as a covariate. Evidence of transfer would be found if we observed a significant effect of group, in which subjects from the two span-training groups improved more from pretest to posttest relative to subjects from the visual search control group. Results of these ANCOVAs are presented in Table 1. We also conducted 3 (group) × 2 (assessment session) mixed analysis of variance and arrived at the same conclusions as with our ANCOVAs.

Near transfer. Performance on the near-transfer tasks is shown in Figure 4. There was a significant increase

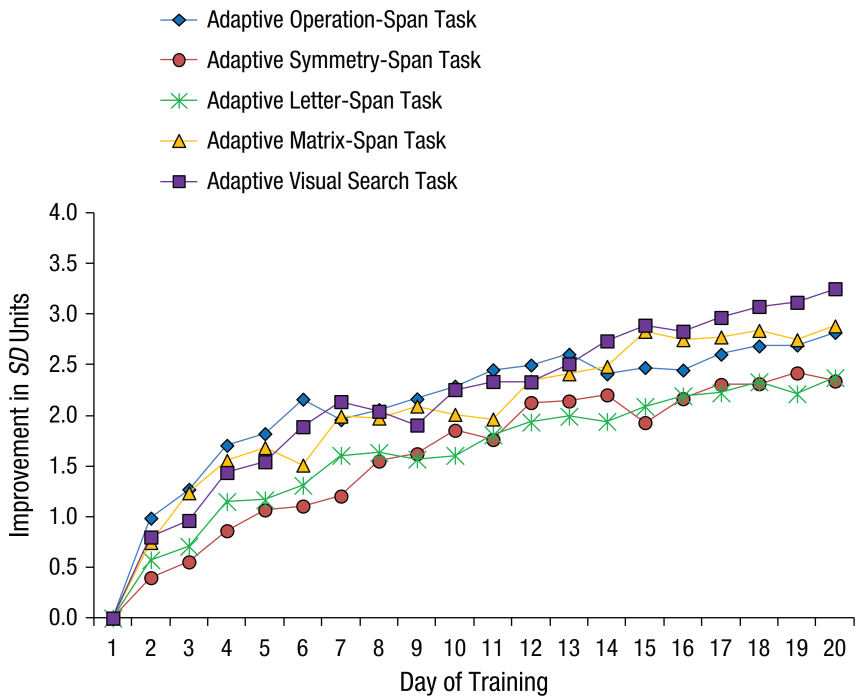

Fig. 3. Performance improvement in the three training groups as a function of training session and task. To calculate performance improvement for each session, we converted the average difficulty level attained on that session to standard-deviation (*SD*) units and subtracted subjects' average performance for their first training session.

from pretest to posttest performance for the complex-span-training group on the rotation- and reading-span tasks, even though both contained different distractor tasks and different to-be-remembered items than the training tasks.

For the word-span and arrow-span tasks, all three groups, including the visual search control group, showed significant improvement from pretest to posttest. However, all groups showed similar improvement. Therefore, we can assume that this benefit was not a result of working memory training. The complex- and simple-span-training groups showed improvement for both the running-letter-span and running-spatial-span tasks. Because the same to-be-remembered stimuli were used for our training tasks and for the running-span tasks, this improvement could be attributable to either an

Table 1. Analysis of Covariance Results for Each Posttest Task

	Group			Pretest performance		
Posttest task	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Reading span	$F(2, 51) = 5.428$	.007	.176	$F(1, 51) = 16.409$	.001	.243
Rotation span	$F(2, 51) = 13.825$	.001	.325	$F(1, 51) = 32.914$	.001	.392
Word span	$F(2, 51) = 1.832$	.170	.067	$F(1, 51) = 25.803$	.001	.336
Arrow span	$F(2, 51) = 2.422$	.099	.087	$F(1, 51) = 24.640$	.001	.326
Running letter span	$F(2, 51) = 4.084$	.023	.138	$F(1, 51) = 18.095$	.001	.262
Running spatial span	$F(2, 51) = 7.251$	.002	.221	$F(1, 51) = 28.930$	.001	.362
Keep track	$F(2, 51) = 6.847$	.002	.212	$F(1, 51) = 18.838$	.001	.270
Visual arrays	$F(2, 50) = 0.232$	.794	.009	$F(1, 50) = 11.066$	.002	.181
Immediate free recall						
Primary memory	$F(2, 51) = 0.403$	.670	.016	$F(1, 51) = 8.043$	.007	.136
Secondary memory	$F(2, 51) = 4.393$	.017	.147	$F(1, 51) = 33.818$	.001	.399
RAPM	$F(2, 51) = 0.418$	.660	.016	$F(1, 51) = 8.192$	.006	.138
Letter sets	$F(2, 51) = 0.959$	.390	.036	$F(1, 51) = 2.745$	.104	.051
Number series	$F(2, 51) = 0.957$	.391	.036	$F(1, 51) = 5.093$	.028	.091

Note: In these analyses, group was a between-subjects variable and pretest performance was a covariate. For the visual-arrays task, $N = 54$ because the program stopped working for 1 subject in the visual search condition; for all other tasks, $N = 55$. RAPM = Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998).

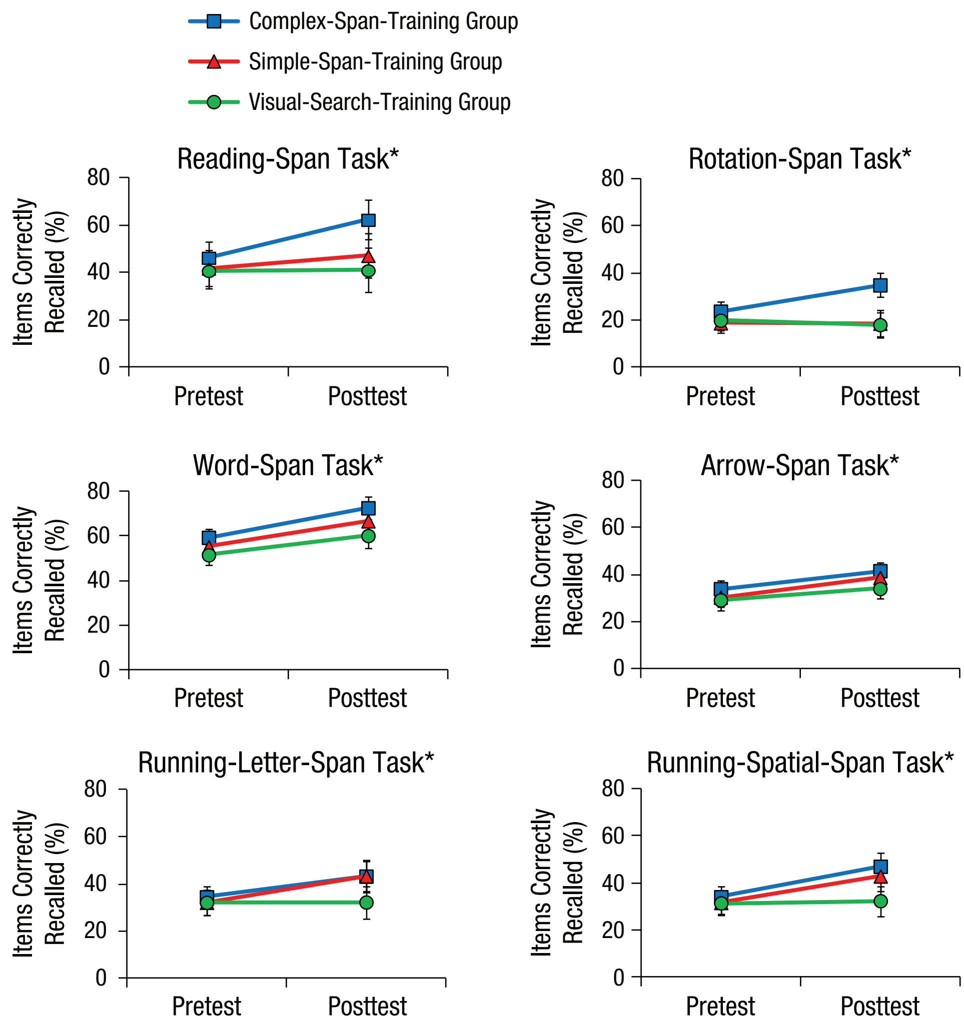

Fig. 4. Results for the near-transfer tasks for each of the three training groups in the pretest and posttest sessions. Each graph shows the percentage of items subjects correctly remembered in serial order. Error bars indicate 95% confidence intervals. An asterisk by the title of the task indicates a significant effect of group in the analysis of covariance (indicating positive transfer of learning from the pre- to posttest sessions; $p < .05$).

increase in WMC or subjects' learning of stimuli-specific strategies for remembering letters and matrix locations.

Moderate transfer. Performance on the moderate-transfer tasks is shown in Figure 5. The secondary memory component of immediate free recall did show benefits of training in both the complex- and simple-span-training groups. Although the keep-track task showed positive transfer for both the complex- and simple-span-training groups, the interaction showed a decrease in performance for the visual search group. Thus, this effect should be cautiously interpreted as evidence for transfer. However, neither the visual-array task nor the primary memory component of immediate free recall showed evidence of transfer.

Far transfer. Performance from the far-transfer tasks is shown in Figure 6. There was no evidence of transfer from any training group for any of the Gf measures. This finding replicates the results of training on the dual *n*-back task (Redick et al., 2013) and on complex span tasks (Chein & Morrison, 2010).

General Discussion

In the study reported here, we showed that 20 days of training on complex span tasks leads to transfer to other complex span tasks that use different to-be-remembered stimuli. For both the complex- and simple-span-training groups, there was some evidence for moderate transfer to the secondary memory component of free-recall and

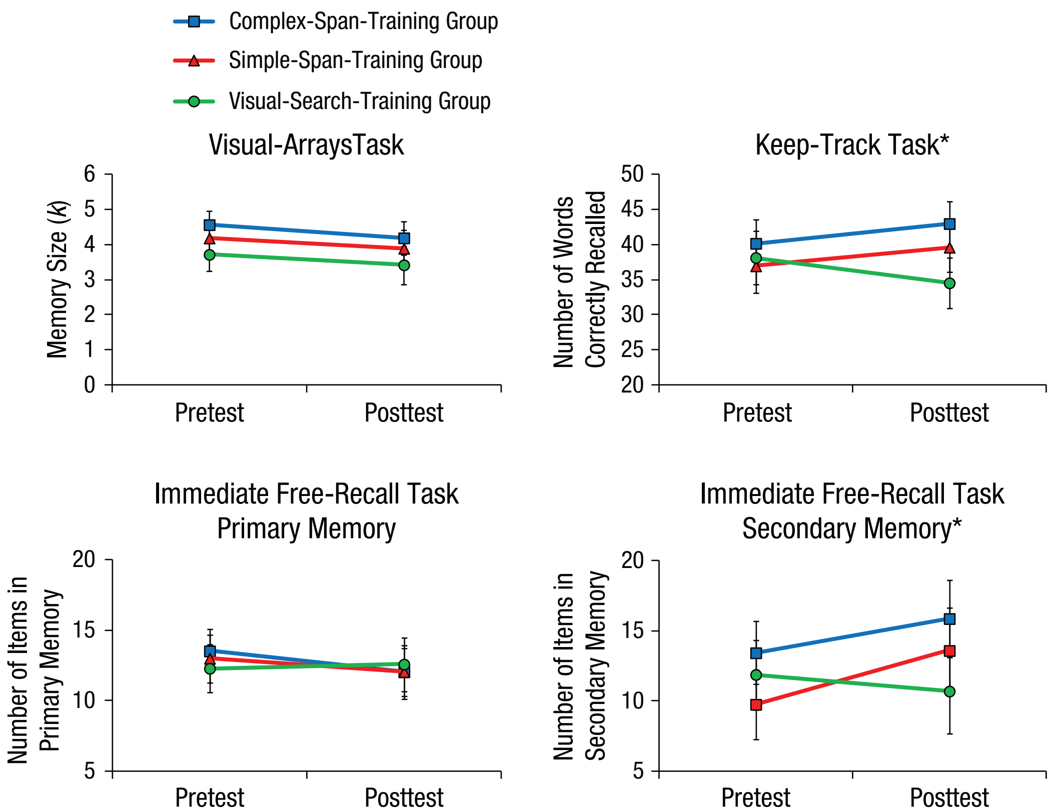

Fig. 5. Results for the moderate-transfer tasks for each of the three training groups in the pretest and posttest sessions. The graphs show estimates of memory size (*k*) for the visual-array task, the number of words correctly recalled in the keep-track task, and the number of items correctly recalled from primary and secondary memory, respectively, in the immediate free-recall task. Error bars indicate 95% confidence intervals. An asterisk by the title of the task indicates a significant effect of group in the analysis of covariance (indicating positive transfer of learning from the pre- to posttest sessions; $p < .05$).

keep-track tasks. These findings imply improvement to WMC at the construct level, but the lack of transfer to other tasks (e.g., the simple span tasks) leads us to be cautious about endorsing this conclusion. There are two other possible interpretations of our data.

First, working memory training could improve only one aspect of WMC. Shipstead, Lindsey, Marshall, and Engle (2013) found that measures of primary memory, secondary memory, and attentional control are required to completely account for individual differences in performance on complex span tasks. Perhaps the working memory training in our study improved only one of those subcomponents of WMC. For instance, the moderate-transfer tasks, on which improvement was not shown, measure the passive maintenance of information. Several of these tasks are thought to reflect primary memory (e.g., the visual-array task and the primary memory score from the immediate free-recall task). However, tasks that required recall of recently activated information from secondary memory (e.g., the keep-track task and the secondary memory score from the immediate free-recall task) did show transfer from both complex-span and simple-span training. These results are consistent with previous research from Gibson and colleagues (2013). When they used the criterion of recalling at least 80% of stimuli during simple-span and complex-span training for subjects to advance to the next level (similar to but less stringent than our 87.5% criterion), Gibson and colleagues found that secondary memory improved on immediate free-recall tasks. Perhaps the working memory training in the present study improved only the secondary memory component of WMC. Future research should address whether any of these subcomponents of WMC is improved by working memory training to clarify exactly what working memory training is accomplishing.

The second possible explanation of our data is that subjects developed strategies that were applicable to certain transfer tasks but not to others. For instance, only the complex-span-training group showed improvement on the reading- and rotation-span tasks. Thus, transfer could be attributable to subjects developing strategies that are specific to complex span tasks. For instance, trained subjects could have learned to rehearse to-be-remembered information during the processing component. Transfer

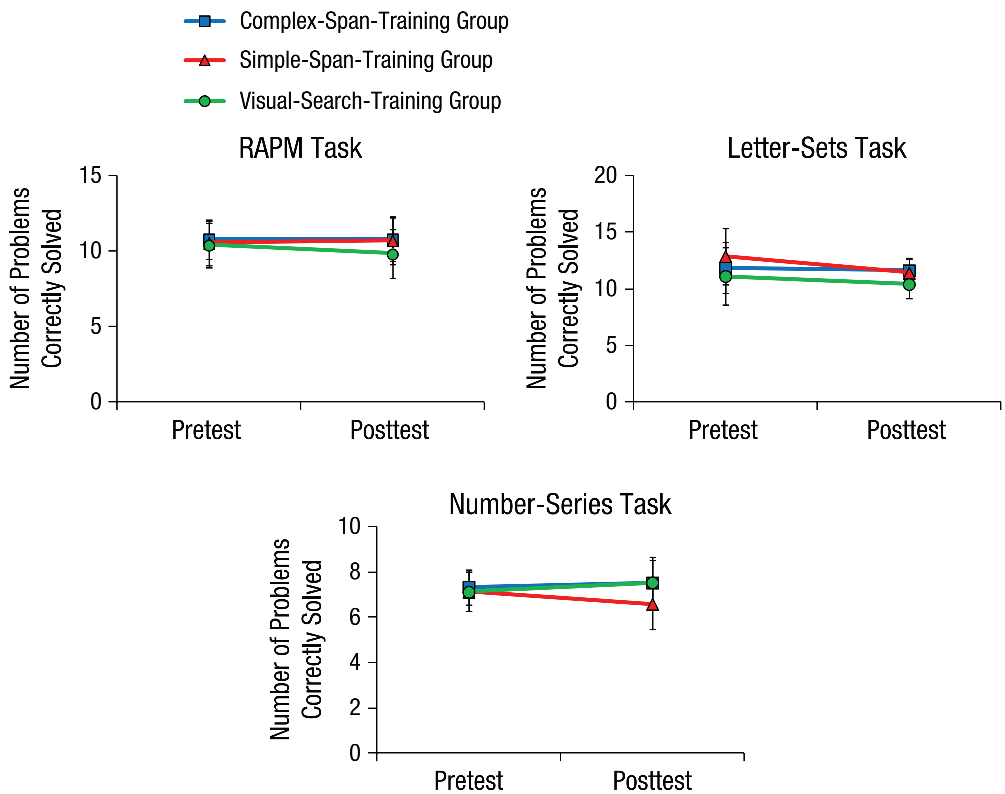

Fig. 6. Results for the far-transfer tasks for each of the three training groups in the pretest and posttest sessions. Each graph shows the number of problems subjects solved correctly. Error bars indicate 95% confidence intervals. RAPM = Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998).

for the running-span tasks could be explained by the overlap in to-be-remembered stimuli between those tasks and the training tasks. Any strategies subjects developed while performing the training tasks (e.g., chunking the letters) could have been applied to the running-span tasks. Therefore, we are cautious about interpreting this as transfer.

Our findings regarding far transfer are clearer. We have repeatedly shown that WMC and Gf are highly related, and it would be easy to conclude that they reflect the same cognitive mechanism. However, we have also made the case that, whereas WMC and Gf are highly related, they are separable constructs (Heitz et al., 2006). The correlation between WMC and Gf is at nearly the same level as weight and height in humans (r = .47 in the latter case; Freedman, Pisani, & Purves, 1998); however, nobody would assume that making someone heavier would also make them taller. The results suggest that WMC and Gf are different hypothetical constructs and that an intervention that may improve WMC may have no effect on Gf.

Future work needs to focus on the mechanisms of working memory training and the extent to which training on certain working memory tasks can improve performance on other tasks that depend on working memory. It is becoming very clear that training on working memory with the goal of trying to increase Gf will likely not succeed (Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012). More important, this focus might cause one to miss the more realistic goal of training those specific strategies and mechanisms of the working memory system important to other aspects of real-world cognition.

Author Contributions

T. L. Harrison, Z. Shipstead, K. L. Hicks, D. Z. Hambrick, T. S. Redick, and R. W. Engle developed the study concept and contributed to the study design. Testing and data collection were performed by Z. Shipstead, K. L. Hicks, and T. L. Harrison. T. L. Harrison analyzed the data, and all authors helped with the interpretation. R. W. Engle and T. L. Harrison drafted the manuscript, and the rest of the authors provided helpful comments for revision. All authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Note

1. We also included two multitasking measures and two personality scales in the pre- and posttest sessions. More information concerning these tasks is reported in the Supplemental Material available online.

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