Psychology and Aging
2010, Vol. 25, No. 4, 767–778

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0882-7974/10/$12.00 DOI: 10.1037/a0020683

Working Memory Training in Older Adults: Evidence of Transfer and Maintenance Effects

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Few studies have examined working memory (WM) training-related gains and their transfer and maintenance effects in older adults. This present research investigates the efficacy of a verbal WM training program in adults aged 65–75 years, considering specific training gains on a verbal WM (criterion) task as well as transfer effects on measures of visuospatial WM, short-term memory, inhibition, processing speed, and fluid intelligence. Maintenance of training benefits was evaluated at 8-month follow-up. Trained older adults showed higher performance than did controls on the criterion task and maintained this benefit after 8 months. Substantial general transfer effects were found for the trained group, but not for the control one. Transfer maintenance gains were found at follow-up, but only for fluid intelligence and processing speed tasks. The results are discussed in terms of cognitive plasticity in older adults.

Keywords: working memory, cognitive training, transfer effects, older adults

Current training studies are seeking ways to enhance and maintain cognitive functioning of older adults through interventions targeting specific processes (see Park, Gutchess, Meade, & Stine-Morrow, 2007) such as inhibition (Davidson, Zacks, & Williams, 2003), executive functions (i.e., updating: Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008; and task switching: Karbach & Kray, 2009), and working memory (WM) (Buschkuehl et al., 2008; Li et al., 2008). Developing such interventions involves determination of the range of modifiability of the targeted functions, the extent to which the trained ability transfers to other tasks, and therefore establishment of whether the benefits are due to the "formation of a new skill, . . . or whether cognitive mechanisms and capacities of general applicability have been enhanced" (Li et al., 2008, pp. 731–732).

Of particular interest is the role of WM in view of its involvement in various different complex abilities such as reasoning (Borella, Carretti, & Mammarella, 2006; de Ribaupierre & Lecerf, 2006; Nettelbeck & Burns, 2010) and reading comprehension (De Beni, Borella, & Carretti, 2007; DeDe, Caplan, Kemtes, & Waters, 2004), as well as its linear decline with aging (Bopp & Verhaeghen, 2005; Borella, Carretti, & De Beni, 2008; Park & Payer, 2006). One of the challenges of aging research is therefore to determine not only whether performance in such a basic cognitive process can be improved, but also whether WM training produces effects that are generalized to untrained tasks and maintained over time.

To date, very few studies have examined the effects of WM training in older adults along with its transfer and maintenance gains. The training procedure is characterized by the presentation of complex tasks for which participants either practice with the task (see, Li et al., 2008) or else advance through the task according to their performance on previous set trials, that is, progress is not automatic (adaptive procedure; see Buschkuehl et al., 2008). The common objective of such training on WM is to seek to improve the information processing system by limiting the development of task-specific strategies in order to favor transfer and long-term effects and overcome the limitations of mnemonic training—which usually shows small or null transfer (Verhaeghen, Marcoen, & Goosens, 1992; but see Carretti, Borella, & De Beni, 2007)—and maintenance effects (e.g., Rebok, Carlson, & Langbaum, 2007; Verhaeghen & Marcoen, 1996), usually attributed to the strategy taught.

Buschkuehl et al. (2008) proposed an adaptive visual WM training program to old-old adults: Their results showed substantial gains in the WM trained tasks. Short- and long-term transfer effects were found only for tasks with the same stimuli content.

Similarly, Li et al. (2008) found in young and older adults specific improvement in the task practiced—a spatial 2 *n-back* WM task–that involved two conditions: one standard, one more demanding. Transfer effects were found on a more demanding 3 *n-back* visual task as well as on numerical *n-back* tasks. Although near transfer effects to the same (visual) and also different (numerical) modality were shown, no far transfer effects to more complex WM tasks (operation and rotation span tests) were found.

With regard to maintenance effects, Buschkuehl et al. (2008) failed to find any maintenance 1 year after completion of training, in comparison with pretest. In contrast, Li et al. (2008) showed a maintenance of practice gains and of near-transfer effects at 3-month follow-up; nonetheless, in contrast with young adults, older participants showed a performance decrement from postpractice to follow-up.

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We wish to thank Sergio Morra for his helpful comments during the preparation of this manuscript.

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Overall, these findings provide evidence for the modifiability of WM performance and coordination processes in young-old and old-old adults, and reveal a degree of cognitive plasticity in aging. However, transfer and maintenance gains, when found, appear to be limited and specific, being mainly related to tasks similar in format to the trained task and specifically share processing requirements with the practice task.

The present study investigates the extent of transfer of WM training in older adults. In previous WM training studies with older adults, the training tasks were visual and the procedure was either adaptive (Buschkuehl et al., 2008) or based on repetitive practice with no adaptation to the participant performance outcome (Li et al., 2008). Instead, in the current study the training stimuli were verbal, and the intervention mixed a particular adaptive procedure with variations in task requests. As with the adaptive procedure, the task difficulty was increased if participants were successful at a given level; however, in the case of failure the lowest level was presented. In addition, in the present training, maintenance and processing requests of the task were systematically varied. This hybrid training procedure was thought to keep the task always challenging and variable, aspects which should favor transfer effects, as pointed out by the literature on training studies (e.g., Gardner, Strayer, Woltz, & Hill, 2000; Karbach & Kray, 2009). We assessed whether WM training of this type produced: (i) performance gains on the criterion task on which participants were trained; (ii) short-term transfer effects (posttest), and (iii) long-term maintenance of gains—at 8 months (follow-up session)—following completion of training.

Because one of the critical issues in training studies is the definition of these effects, in particular the range of transfer distance (e.g., Noack, Lövdén, Schmiedek, & Lindenberger, 2009), the effects were categorized along a conceptually based continuum of nearest- to far-transfer tasks. Common measures used in cognitive aging research, and theoretically related to WM, were chosen: short-term memory, fluid intelligence, inhibition, and processing speed (Craik & Salthouse, 2000; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). For nearest-transfer effects, a visuospatial WM task (Dot Matrix task; adapted from Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) was included. This task involves processes (elaboration and processing phase) similar to the one practiced. However, the nature of the material and the secondary requirement are different from those of the trained task. The Forward and Backward Digit Span tests were used to assess near-transfer effects because they are part of the general memory factor, but the task requests were different from those of the WM tasks (see Bopp & Verhaeghen, 2005). Because these tasks measure the same narrow or same broad ability, we expect transfer effects onto them. To determine the presence of far transfer effects, we chose classic tasks: the Cattell task to measure nonverbal reasoning ability; the Stroop Color test to index inhibition-related mechanisms; and the Pattern Comparison test to assess processing speed. The transfer abilities were chosen with consideration of their relationship to WM processes. Working memory impairment in older adults is generally attributed to general mechanisms such as inhibition and processing speed (Borella et al., 2008). Furthermore, WM is frequently advanced as one of the mechanisms that also accounts for age-related differences in intelligence tasks (de Ribaupierre & Lecerf, 2006; Rabbitt & Lowe, 2000; Schaie & Hertzog, 1986), because WM and intelligence share a limited processing capacity that has to keep a certain amount of information simultaneously active (Kyllonen & Christal, 1990) and, more generally, because both require controlled and effortful processing (Salthouse, Pink, & Tucker-Drob, 2008).

Given that these tasks tap mechanisms related to WM process functioning in older adults, theory would lead us to expect far-transfer effects, despite the failure to find such effects in previous studies (e.g., Buschkuehl et al., 2008; Li et al., 2008). In addition the magnitude of modifiability of untrained tasks was evaluated, given that the tasks selected vary in degree of processing overlap with the practice task.

Method

Participants

Forty older adults, aged 65-75 years, participated in the study; 20 (13 women and 7 men) were randomly assigned to the trained group; the remaining 20 (10 women and 10 men) were assigned to the control group.

All participants were healthy, native Italian speakers and volunteered for the study; they were selected on the basis of a physical and a health questionnaire. None fitted the "exclusion criteria" proposed by Crook et al. (1986): that is, history of head trauma; any neurological or psychiatric illness; history of brain fever; dementia or any other state of consciousness alteration; use of benzodiazepines in the previous 3 months; use of illicit drugs; visual, auditory, or motor impairment; and any symptomatic cardiovascular condition, breathing problems, or pathologies causing possible cognitive impairments. They were recruited from the University of the Third Age or in social clubs in Mestre (Venice, Italy); they were active in the cultural and social activities of their neighborhoods.

Experimental and control group participants did not differ ($p > .05$) in age, years of formal education, or *Wechsler Adult Intelligence Scale—Revised* (*WAIS–R*) vocabulary score (Wechsler, 1981). Demographics for each group are listed in Table 1.

Materials

Criterion task. The Categorization Working Memory Span task (CWMS; Borella et al. 2008; De Beni, Borella, Carretti, Marigo, & Nava, 2008) is similar to the classic WM tasks, such as the Listening Span test (Borella et al., 2008), the only difference being that it involves processing lists of words rather than sentences, limiting the role of semantic processing. The materials

Table 1
Demographic Characteristics of the Trained and Control Groups

	Trained group (N = 20)		Control group (N = 20)	
Characteristic	*M*	*SD*	*M*	*SD*
Age	69.00	3.18	69.15	2.99
Education	9.40	3.95	9.25	3.54
Vocabulary	46.65	8.64	44.60	9.23

consisted of 10 sets of words, each set comprising 20 lists of words, which were organized in series of word lists of different lengths (from 2 to 6). Each list contained 5 words of high–medium frequency. Furthermore, the lists contained zero, one, or two animal nouns, present in any position, including last. An example list is *house, mother, dog, word, night*. Of the total number of words (200) in the task, 28% were animal words.

Participants listened to the lists of words audiorecorded presented at a rate of 1 s per word and had to tap their hand on the table whenever they heard an animal noun (processing phase). The interval between series of word lists was 2 s (the presentation was thus paced by the experimenter). At the end of the series, participants recalled the last word of each string in serial order (maintenance phase). Two practice trials of 2-word length were given before the experiment started.

Words recalled were written down by the experimenter on a prepared form. The total number of correctly recalled words was used as the measure of WM performance (maximum score 20). This score has been demonstrated to show large correlations with visuospatial (Jigsaw Puzzle test) and verbal (Listening Span test) WM tasks (Borella et al., 2008), and measures of fluid intelligence (Borella et al., 2006).

Half (five) of the sets were used as a pretest task, the other five as posttest. The two sets were counterbalanced across testing sessions.

Nearest-transfer effects: Visuospatial WM task. The Dot Matrix task (adapted from Miyake et al., 2001) is a computerized WM task that differs from the trained task in terms of: (i) the nature of the materials (visuospatial), and (ii) the secondary requirement, that is to verify equations rather than to tap on hearing an animal word.

Participants had to verify a simple visual matrix equation, checking whether it was true or false while simultaneously remembering a dot location on a 5 ×5 grid. Each trial contained a set of matrix equations for verification that consisted of either addition or subtraction presented as lines drawn on a 3 ×3 matrix. Participants were given a maximum of 4.5 s to verify each equation by saying “True” or “False.” Immediately after each response, participants were then given a 3-s presentation of a 5 × 5 grid containing a dot in one of its squares. After a sequence of between two and six equation-grid pairs, they had to indicate on a blank 5 × 5 grid the sequence that had contained the dot. There was one practice trial with two equations, each with one dot. The test was carried out at five levels (Levels 2 to 6). A total of 28 equations and 28 matrices were presented.

Positions recalled were written down by the experimenter on a prepared form. The total number of dot positions correctly recalled was considered as a dependent variable (maximum score of 14).

Half (14) of the sets were used at pretest, the other 14 at posttest in a counterbalanced fashion across testing sessions.

Near-transfer effect: Short-term memory tasks. In the Forward Digit Span and Backward Digit Span tasks (De Beni et al., 2008), series of digits were presented at a rate of 1 s per digit; participants had to repeat the digits in the same (forward) or reverse (backward) order. The series started from three digits and rose to nine for the forward task, and went from two to eight for the backward task. Each level contained two strings of digits. After two consecutive recall errors, the task was discontinued. A practice sequence of two digits was given for each task before the test started. One point was awarded for each sequence correctly recalled.

The final score corresponded to the total number of correct trials recalled (maximum score of 14 for both tasks).

For each task, two versions were created, exchanging the digit strings within each level; one was administered at pretest, the other at posttest in counterbalanced fashion across testing sessions.

Far-transfer effects: Fluid intelligence (Cattell test), inhibition-related processes (Stroop Color task), and processing speed (Pattern Comparison test).

Culture Fair test, Scale 3 (Cattell & Cattell, 1963). Scale 3 of the Cattell test consists of two parallel forms (A and B), each containing four subtests to be completed in 2.5 to 4 min, depending on the subtest. In the first subtest, Series, participants saw an incomplete series of abstract shapes and figures and had to choose from six alternatives that best completed the series. In the second subtest, Classifications, participants saw 14 problems comprising abstract shapes and figures and had to choose which 2 of the 5 differed from the other 3. In the third subtest, Matrices, participants were presented with 13 incomplete matrices containing four to nine boxes of abstract figures and shapes plus an empty box and six choices: Their task was to select the answer that correctly completed each matrix. In the final subtest, Conditions, participants were presented with 10 sets of abstract figures, lines, and a single dot, along with five alternatives: Their task was to assess the relationship among the dot, figures, and lines, then choose the alternative in which a dot could be positioned in the same relationship.

The dependent variable was the number of correctly solved items across the four subsets (maximum score of 50).

One of the two parallel forms (A or B) was administered at pretest, the other at posttest in counterbalanced fashion across testing sessions.

Stroop Color task (adapted from Trenerry, Crosson, De Boe, & Lever, 1989). The task, administered in paper modality, consisted of six cards. The first two cards contained names of colors printed in an incongruent ink color (Incongruent condition). The third and fourth cards contained names of colors printed in a congruous ink color (Congruent condition). Finally, two cards containing color patches were presented (Control condition). Participants had to name the ink color of each stimulus and were required to process stimuli as fast as possible whilst being as accurate as possible. The experimenter recorded response latencies for all conditions by using a stopwatch as times between naming first and last stimuli, as is typical in other studies using the paper version (e.g., Troyer, Leach, & Strauss, 2006; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006; West & Alain, 2000), and noted accuracy by hand on a prepared form. An interference effect was calculated as the relative difference, to control for individual difference in baseline (e.g., Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009), between Incongruent and Control conditions calculated for time and errors as follows: (incongruent condition − control condition)/control condition. A higher score thus implies greater difficulty in controlling the prepotent response in the incongruent condition.

Two versions of the task were created by exchanging card order within each condition; one was administered at pretest, the other at posttest in counterbalanced fashion across testing sessions.

Pattern Comparison task (adapted from Salthouse & Babcock, 1991). In this task, participants had to decide whether arrangements of line segments were identical or not. The items to be compared were set out on two pages, each containing one column of 30 items. Responses consisted of writing *S* (for *Si*, i.e., *Yes*, for identical) or *N* (for *No*, for different) on the line between the two members of each stimulus pair. The experimenter used a stopwatch to record the time to complete each page. Three practice trials were given before the experiment started. The dependent variable was total time taken to complete responses for the two pages.

Two versions of the task were created by exchanging page order; one was administered at pretest, the other at posttest in counterbalanced fashion across testing sessions.

Procedure

Participants of the trained and control groups attended five individual sessions: The first and last sessions were the pretest and the posttest; in the other three, the control group carried out alternative "activities," as described below, while the trained group attended the training itself. Each session lasted about 60 min; the training was completed within a 2-week time frame, with a fixed 2-day break between training sessions. The schedule was identical for the two groups, thus allowing amount of social interaction to be matched.

The WM training consisted of three sessions (Sessions 2, 3, and 4) in which participants were trained on modified versions of the CWMS task. The experimenter presented participants of the trained group with lists of words, audiorecorded and organized as for the CWMS task. Again, as for the CWMS task, the basic instructions were to recall the target words (see below) and tap the hand on the table whenever an animal noun arose. However, some manipulations were made during the three sessions to favor generalized transfer and limit the development of task-specific strategies. The maintenance demand of the CWMS task was manipulated by increasing the number of words to be recalled in the case of success, and presenting the lowest memory load in the case of failure (Session 2). Moreover, the task requests were varied, requiring recall of: (i) the last or first word of each series (Sessions 2 and 4), and (ii) words that were followed by a *beep* sound (Session 3). The processing request, tapping for occurrence of an animal noun, was also manipulated by varying the frequency of these animal words in the lists (Session 3).

There were no instructions to use specific strategies, and no feedback was provided.

For the trained group the five sessions were organized as follows:

- In Session 1 (pretest session), participants were given the following tasks (listed in order of presentation): Vocabulary, Forward Digit Span, Backward Digit Span, Pattern Comparison, CWMS, Stroop Color, Dot Matrix, and Cattell. The order of presentation was fixed for each participant. The CWMS was presented in auditory modality (audiorecorded), the Dot Matrix was computerized, the Stroop Color was in paper modality, and the Vocabulary, Pattern Comparison, and Cattell tests were in paper-and-pencil format.

Furthermore, before starting this and the training sessions, in order to limit the influence of sensory variables (sight and hearing) on the outcomes, the auditory presentation was adjusted to the participant's hearing level. Also, for the paper-and-pencil tasks, all participants were asked whether they found it easy to read the stimuli.

- In Session 2, series of word lists were grouped into sets of different lengths (from 2 to 5), each with three series of word lists. The task included three phases presented sequentially: In the first phase, the experimenter instructed participants to recall the last word of each series of words; in the second phase, the first word of each series; and in the third phase, again the last word.

The session always began from the first phase (recall of the last word of each series of words) and from the length 2 set. In the case of success (correct recall of words for two of the three series), the task was increased in difficulty up to length 5. Once the final level was reached, phase 2 (requiring recall of the first word) was presented, starting from the lowest level of memory load (i.e., length 2). In the case of success in all second-phase trials, the third phase (recall of the last item) was administered, starting again from the lowest level (2).

However, in the case of failure, the level of difficulty was not increased, and the following phase was started. For example, if participants failed at level 3 of the first phase, they started the second phase from level 2; if they succeeded here, the level of difficulty was increased, whereas for failure there was again a change of phase (the third). The new phase always started from the lowest level (2). The experimenter ended the task when, at phase 3, the participant failed to correctly recall the final words of two out of the three series. Of the total number of words (185) per task part, 20% were animal words.

- In Session 3, series of word lists audiorecorded were grouped into sets of different lengths (from 2 to 5), each consisting of four series of word lists. For each length, the first two series contained fewer animal words than did the last two. Specifically, word series of length 2 could contain from 2 to 8 animal nouns; length 3, from 4 to 9; length 4, from 6 to 11; and length 5, from 8 to 17. For each series, participants were instructed to remember each word that was followed by a *beep*, in serial order. The task difficulty was not adjusted to participant performance. Of the total number of words (280) included in the task, 55% were animal words.
- In Session 4, participants had to recall alternately words in last, then first, position on the list. The task started with a set of four series of two-word lists, the requirement for the first series being to recall the last words of each list; for the second series, the first words; for the third series, the last words; and for the fourth series, the first words. The memory load increased progressively from two to five, independently of participant performance (correct or incorrect recall). Of the total number of words (280) included in the task, 20% were animal words.
- In Session 5 (posttest session), participants were administered the same tasks (except for the Vocabulary test) as in Session 1, with the same presentation order.

Control group participants met the experimenter and underwent the same number of sessions as did the trained group for approximately the same amount of time. Sessions 1 and 5 were the same as for the trained group. However, in Sessions 2, 3, and 4, participants were required to complete a questionnaire in which they had to try to remember common events related to their childhood, adulthood, and recent events, and to rate their vividness (Autobiographic Memory Questionnaire, De Beni et al., 2008; Session 2); rate the frequency of behavior dedicated to saving memories of life events (Memory Sensitivity Questionnaire, De Beni et al., 2008; Session 3); and rate personal satisfaction about life (past, present, and future), emotional competencies (ability to understand one's own and other's emotions), and coping strategies regarding everyday problems (Questionnaire of Psychological Well-Being, De Beni et al., 2008; Session 4). Questionnaires were administered in paper-and-pencil format.

For both trained and control groups, the sessions were guided by the experimenter, who explained the activities of each session and managed the presentation of materials (i.e., stopping the tape-recorder to allow participants to recall the words). Sessions ended with the experimenter asking participants their feelings about the activities carried out and reminding them about the date of the following meeting.

All participants took part in an 8-month follow-up maintenance session, in which the tasks, in pretest versions, were administrated in the same order.

Results

First, in order to interpret differences between the two groups on the training procedure, separate analyses of variance (ANOVAs) were carried out with group (trained and control) as the between-subjects factor on the pretest performance on all tasks. Results indicated that there were no baseline differences between the trained and control groups (see Table 2).

To assess training effects, we analyzed the measures of interest for each task using a 2 Group (trained and control) × 3 Session (pretest, posttest, and follow-up) mixed-design ANOVA with group as a between-subjects factor and session as repeated measures. Interactions were decomposed using post hoc pairwise comparisons with Bonferroni's correction at $p < .05$, adjusted for multiple comparisons. Descriptive statistics are given in Table 2, and the ANOVA results are summarized in Table 3.

For the Stroop Color task, in view of the very low/null number of errors, analyses were run only on interference index for response times (RTs).

Criterion Task: CWMS

Trained participants recalled more correct words than did controls (*Mdiff* = 4.23, $p < .001$). Performance consistently increased from pretest to posttest and follow-up (*Mdiff* = −2.65, $p < .001$, and *Mdiff* = −2.82, $p < .001$, respectively), the latter not differing between each other. Post hoc comparisons revealed that trained participants performed better at posttest ($p < .001$) and follow-up ($p < .001$) than at pretest. Furthermore, this group maintained performance from posttest to follow-up. By contrast, no significant difference was found for the control group. The trained group outperformed the control group at both posttest and follow-up ($p < .001$).

The trained group performed better at posttest than at pretest, and the performance increased from pretest to 8-month follow-up.

Transfer Effect

Nearest-transfer effect. For the Dot Matrix task, all participants performed better at posttest and follow-up than at pretest (*Mdiff* = 1.70, $p < .001$, and *Mdiff* = 0.67, $p < .01$, respectively); however, from posttest to follow-up, performance fell (*Mdiff* = −1.02, $p < .01$).

For the trained group, post hoc comparisons indicated an improvement in performance between pretest and posttest ($p < .001$) and a decrease between posttest and follow-up ($p < .001$). No significant difference was found from pretest to follow-up for the trained participants. For the control group, performance did not differ between sessions. The two groups differed only in posttest performance ($p < .001$).

Near-transfer effect. In the Forward Digit Span test, the trained group recalled significantly more correct digits than did the control group (*Mdiff* = 1.18, $p < .001$). For the two groups, performance was significantly higher at posttest than at pretest

Table 2
Descriptive Data for Pretest, Posttest and Follow-Up Data by Group

	Trained group						Control group					
	Pretest		Posttest		Follow-up		Pretest		Posttest		Follow-up	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
CWMS	9.60	3.25	15.45	1.54	14.75	1.41	9.05	4.22	8.50	3.57	9.55	3.96
Dot Matrix	5.70	2.13	8.90	1.52	6.5	2.04	6.15	2.25	6.35	2.11	6.70	1.63
Forward Span	6.65	0.99	8.45	0.51	6.35	0.49	6.40	1.47	5.65	1.14	5.85	1.18
Backward Span	5.30	0.98	7.60	0.94	5.54	0.51	5.55	1.54	5.10	1.07	5.40	0.94
Cattell	16.00	4.79	22.05	3.59	20.30	2.92	15.70	4.16	16.54	5.29	16.55	4.36
Stroop Color incongruent RTs	31.58	5.88	22.88	3.51	24.37	3.24	33.50	8.28	32.25	7.57	31.47	8.34
Stroop Color control II RTs	15.35	3.44	13.05	1.81	12.32	2.10	15.95	4.67	15.66	4.32	15.77	4.46
Stroop Color index on RTs	1.10	0.39	0.78	0.35	1.01	0.35	1.15	0.37	1.09	0.34	1.03	0.33
Stroop Color incongruent errors	1.10	1.62	0.15	0.37	0.00	0.00	1.30	1.52	0.85	0.81	1.15	1.27
Stroop Color control II errors	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pattern Comparison	174.60	40.35	135.55	36.75	146.85	33.70	188.01	30.34	186.50	28.99	182.43	30.01

Note. CWMS = Categorization Working Memory Span test; RTs = response times.

Table 3

Mixed-Design 2 × 3 ANOVA Results for the Measures of Interest, With Group (Trained, Control) as Between-Subjects Factor and Session (Pretest, Posttest, Follow-Up) as Repeated Measures

Measure	*F*(1, 38)	*MSE*	η_{p}^2
Specific effect			
CWMS			
Between subjects			
Group	20.71***	8.65	0.35
Within subjects			
Session	42.77***	2.34	0.53
G × S	46.69***	2.34	0.55
Transfer effects			
Dot Matrix			
Between subjects			
Group	1.35	2.69	0.03
Within subjects			
Session	21.70***	2.34	0.36
G × S	20.51***	2.34	0.35
Forward Digit Span			
Between subjects			
Group	19.48***	0.72	0.34
Within subjects			
Session	18.26***	0.49	0.32
G × S	39.83***	0.49	0.51
Backward Digit Span			
Between subjects			
Group	8.53***	0.69	0.18
Within subjects			
Session	19.27***	.59	0.34
G × S	38.43***	.59	0.50
Cattell test			
Between subjects			
Group	7.58***	13.65	0.16
Within subjects			
Session	18.78***	6.69	0.33
G × S	10.80***	6.69	0.22
Stroop Color interference index			
Between subjects			
Group	2.07	0.22	0.05
Within subjects			
Session	4.14*	0.80	0.10
G × S	3.34*	0.80	0.08
Processing speed			
Between subjects			
Group	12.97***	855.51	0.25
Within subjects			
Session	11.38	411.00	0.23
G × S	8.67***	411.00	0.19

Note. ANOVA = analysis of variance; CWMS = Categorization Working Memory Span test; G = group; S = session.
$^{*}p < .05$. $^{***}p < .001$.

(*Mdiff* = 0.52, $p < .001$). Nevertheless, a higher number of correct digits at both pretest and posttest was recalled than at follow-up (*Mdiff* = 0.42, $p < .001$, and *Mdiff* = 0.95, $p < .001$, respectively). Post hoc comparisons revealed that only the trained group showed a consistent increase in performance between pretest and posttest ($p < .001$), whereas at follow-up, performance was not different from that at pretest. A decrease in performance between posttest and follow-up ($p < .001$) was also found for the trained participants. For the control group, performance did not differ between sessions. The trained group performed better than did the control group only at posttest ($p < .001$).

In the Backward Digit Span test, the trained group performed better than did the control group (*Mdiff* = 0.77, $p < .001$). Participants performed significantly better at posttest than at either pretest (*Mdiff* = 0.92, $p < .001$) or follow-up (*Mdiff* = 0.92, $p < .001$), but no significant difference was found from pretest to follow-up. Although for the control group no significant differences were found across test occasions, the trained group showed a significant increase in performance between pretest and posttest ($p < .001$). Even so, for the trained participants a significant decrease between posttest and follow-up ($p < .001$) was found, and the comparison between pretest and follow-up was not significant. The trained group performed better than did the control group only at posttest ($p < .001$).

For the visuospatial WM tasks and the two short-term memory tasks, trained participants did not maintain immediate transfer over time, performing at a level similar to that at pretest.

Far-transfer effect. For the Cattell test, results indicated that trained participants performed significantly better than did controls (*Mdiff* = 3.22, $p < .001$). Posttest and follow-up performances were significantly better than on pretest (*Mdiff* = 3.40, $p < .001$, and *Mdiff* = 2.75, $p < .001$, respectively). No significant difference was found between posttest and follow-up. Post hoc comparisons revealed that only the trained group showed significant improvement in performance between pretest and both posttest ($p < .001$) and follow-up ($p < .001$), although posttest performance was not different from that of follow-up. By contrast, no significant difference was found for the control group. The trained group performed better at both posttest and follow-up than did the control group ($p < .001$).

With regard to the Stroop Color interference index, all participants showed stronger resistance to interference at posttest than at pretest (*Mdiff* = 0.18, $p < .01$). Post hoc comparisons indicated that trained participants, but not control ones showed stronger resistance to interference at posttest than at pretest ($p < .01$), whereas the trained group showed stronger resistance to interference than did the control group only at posttest ($p < .001$). No other difference was significant for the two groups.

Finally, for the Pattern Comparison test, the trained group completed the task more quickly than did the control group (*Mdiff* = 33.31, $p < .001$). For both groups, completion times were shorter at both posttest and follow-up than at pretest (*Mdiff* = 20.27, $p < .001$, and *Mdiff* = 16.65, $p < .001$, respectively); no significant difference was found between posttest and follow-up. Post hoc comparisons indicated that the trained group, but not the control group, showed a significant decrease in time to complete the task between pretest and posttest ($p < .001$), and between pretest ($p < .001$) and follow-up, although posttest performance was not different from that of follow-up. No significant difference was found for the control group. The trained group performed better at both posttest and follow-up than did the control group ($p < .001$).

Trained older adults showed immediate transfer effect. After the training, on the Cattell and Pattern Comparison tasks, they also performed better than at pretest. However, the immediate transfer effect for the Stroop Color interference index was not maintained over time.

To obtain a closer understanding of the range of training gains and transfer effects between pretest and posttest, Cohen's (1988) *d* —expressing the effect size of the comparisons—was calculated. Values were corrected using the Hedges and Olkin (1985) correction factor to avoid the small sample bias. Comparisons of the gains from pretest to posttest within each group revealed a large (above .80) effect size in the case of the trained group, and a small effect size for the control group (see Figure 1).

For the pretest and follow-up, effect sizes were large for the Criterion task (CWMS, $d = 2.01$) and Cattell test ($d = 1.12$), and medium for the Pattern Comparison task ($d = 0.73$).

Discussion

Summary of Findings

The study investigated the transfer effects of a verbal WM training program in older adults, along with the maintenance of gains. It was found that the WM training benefits were indeed effective, with only the trained group showing both specific gains (on the Criterion task) and transfer gains. Evidence was found for substantial and immediate posttraining effects of transfer not only to similar abilities but also to abilities dissimilar but theoretically related to WM. The magnitude of the effects was in fact large, as was demonstrated by the values of the *d* index (Cohen, 1988). Moreover, the training benefit gains are also supported by a decrease of variability (standard deviation) for the trained group, indicating an overall increase in test performance after the intervention. Transfer effects were found for tasks that represent a same narrow ability (visuospatial WM task); different narrow but same broad ability (short-term memory tasks); and different abilities (fluid intelligence, inhibition, and processing speed tasks). In contrast, control group gains were very limited or null in comparison with those of the trained group. This pattern of findings clearly indicates that trained-group benefits cannot be interpreted as simple test–retest effects or as due to individual differences. Furthermore, because different task versions were used from pretest to posttest, transfer effects are unlikely to be due to item-specific practice effects.

Transfer Effects

Our results are somewhat surprising given that previous WM training studies failed to find transfer effects, except for the practiced task or tasks closely sharing processes with it. One potential source of these transfer effects may be the training procedure adopted, which may have produced a change in the allocation of attentional resources to enable efficient handling of the different task demands of the transfer tasks (e.g., Jennings, Webster, Kleykamp, & Dagenbach, 2005; Schmidt & Bjork, 1992). The training program provided an adaptive and repetitive regimen for participants, with repeated practice and gradual increase of difficulty: The WM training task difficulty was in fact manipulated by changing the amount of information to be recalled (Session 2) or by varying the processing (Sessions 3 and 4) and maintenance requests (Phase 2 of Session 2, and Sessions 3 and 4), thus forcing participants to quickly adapt to new task requests. Such a procedure ensures that the task is always challenging, cognitively demanding, and novel, thus probably requiring participants to adhere to the task. Schmidt and Bjork (1992) have argued that challenging training conditions often promote generalization. Furthermore, it is clear that our practice task engages multiple processes including encoding, maintenance of information, inhibition of no-longer-relevant information, simultaneous management of two tasks, shifting attention, and ability to control attention. Thus, assuming that all these processes were trained, it is logical that transfer effects would be obtained. In the domain of executive functions, it has been shown that if the training paradigm is flexible and variable, transfer occurs (e.g., Kramer, Larish, & Strayer, 1995). For instance, Kramer et al. (1995) found transfer effects when

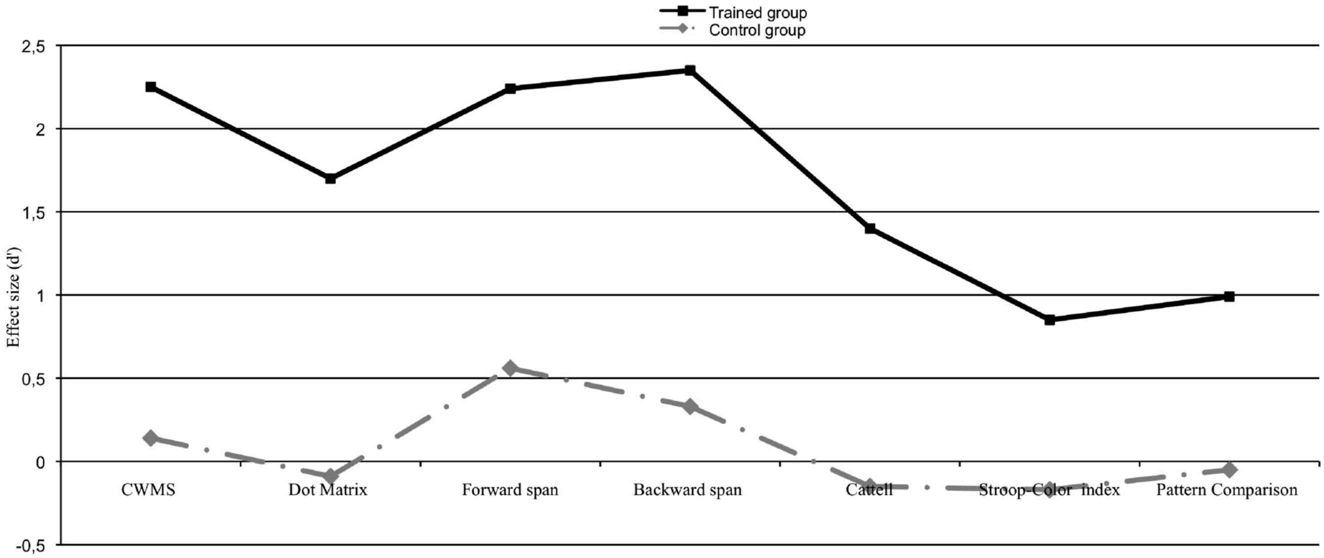

Figure 1. Effect size *d* for pre- and posttest contrasts for transfer effects (nearest, near, and far) as a function of transfer measure and group (trained and control). CWMS = Categorization Working Memory Span test.

older participants were instructed to rapidly shift priority among concurrent tasks (variable priority condition); however, effects were not found when they were asked to treat the concurrent task demand as equal in importance. Consistently, Karbach and Kray (2009) found robust transfer effects on verbal and visuospatial WM, fluid intelligence, and interference control in the Stroop Color task in children, young adults, and older adults after task-switching training. Basak, Boot, Voss, and Kramer (2008) found transfer effects after videogame training for some executive control tasks such as task switching, focus switching in *n*-back, and visual short-term memory. It is worth mentioning that in this study, no transfer effects after a 23-hr training were found for a complex span test (the operation span test) or for other executive control tasks/measures (e.g., stop signal, accuracy on the *n*-back and task switching, enumeration, attentional blink, and mental rotation latency).

The present findings, however, contrast with the outcome of the WM training studies conducted with older adults (Buschkuehl et al., 2008; Li et al., 2008), in which no transfer effects were found either to other complex WM span tasks (Li et al., 2008) or to tasks with different memory content (Buschkuehl et al., 2008). This discrepancy cannot be due to the tasks selected to determine transfer effects, because some were similar across our study and previous investigations (short-term memory tasks, Buschkuehl et al., 2008, and complex WM tasks, Li et al., 2008). However, some sources of difference between our study and earlier investigations can be identified.

First, the participants involved in our study were young-old (mean age of 69 years), whereas in Buschkuehl et al.'s (2008) study as well as that of Li et al. (2008), they were old-old adults (mean age of 80.1 and 74.5 years, respectively). In the context of episodic memory, the meta-analysis by Verhaeghen et al. (1992) has pointed out that the benefit of interventions is negatively related to participant age (see also Singer, Lindenberger, & Baltes, 2003). It has been shown that cognitive plasticity is reduced over the adult life span (Jones et al., 2006), with young-old exhibiting larger training-related gains than old-old (Singer et al., 2003). The importance of participant age is evident from considering the results of training focused on executive control tasks–for example, task-switching (Buchler, Hoyer, & Cerella, 2008; Karbach & Kray, 2009; Kramer, Hahn, & Gopher, 1999), dual tasks (Bherer et al., 2005, 2008), or general executive functions (Basak et al., 2008)—for which transfer effects emerged with a sample comprising young-old (age range between 60 and 75 years, mean age between 65 and 71 years; Basak et al., 2008; Bherer et al., 2005, 2008; Karbach & Kray, 2009; Kramer et al., 1995). The question of whether transfer effects of WM training can also be determined by participant age range is of interest and should be addressed in further research.

Second, as is mentioned at the beginning of this section, the task and the procedure used to train participants can be considered an important source of difference. For example, Buschkuehl et al. (2008) reported that trained participants claimed to have generated task-specific strategies in one of the variants of the WM task in which they were trained, leading to greater training gains (62%) with respect to the other two variants (44% and 15%, respectively). The difficulty of transferring the gains obtained in a specific task to other tasks suggests that the WM training by Buschkuehl et al. did not foster an increase in flexibility, but simply the tendency to find a strategy to recall as many items as possible but in the context of each WM task. In the case of Li et al. (2008), the modest transfer effects to the WM task can be explained by reflecting on the nature of the trained task: *n*-back task, which involves the manipulation and maintenance of information as well as updating of temporal order and contextual information and binding processes between stimuli and certain representation (Oberauer, 2005). Although the *n*-back shares common processing mechanisms with complex span tasks, the underlying mechanisms of the *n*-back are not completely understood (Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009). Moreover, the few studies that used it with other WM tasks—complex span tasks—have shown variable correlations (from very low or null-Kane, Conway, Miura, & Colflesh, 2007; Roberts & Gibson, 2002–to large–Schmiedek et al., 2009; Shamosh et al., 2008).

Finally, our training consists of just three 1-hr sessions, in comparison with larger numbers of training sessions used in the other WM training studies: 24 sessions (2 per week, for 12 weeks) for Buschkuehl et al. (2008), 45 (15 min per day) for Li et al. (2008). Although obtaining transfer effects after such brief training may appear counterintuitive, its intensive nature, concentrated in terms of a timescale, may have facilitated the short-term transferability of WM training to other tasks, allowing participants to maintain their interest toward the training activities. Indeed, other successful training studies involving few training sessions can also be found in the literature. For example, Karbach and Kray (2009) found significant transfer effects in older adults with a training of four sessions (each lasting 60–70 min). Kramer et al. (1995) as well as Bherer et al. (2005), in dual-task training, also proposed limited numbers of training sessions (three and five, respectively), showing transfer effects in different sets of stimuli and tasks. Furthermore, in the domain of episodic memory training, intensive (concentrated in time) interventions (e.g., Stigsdotter Neely & Backman, 1995) have been shown to have slighter performance advantages than do briefer interventions (e.g., Verhaeghen et al., 1992). Future studies should investigate variability of dose, frequency, and intensity of training that produces benefits.

Another important variable might be the training setting, in particular regarding the presence/absence of the experimenter during the sessions. In Buschkuehl et al. (2008), participants were tested individually at pretest and posttest, while the training was conducted in small groups (of 8 participants) under the experimenter's supervision, with the training tasks carried out at a PC. Interaction was thus limited to the initial and final parts of the sessions. No explicit information is given in the study by Li et al. In our training program, the experimenter guided the entire session in a one-to-one interaction. The presence of human–human interaction, in contrast to machine–human interaction, might have led to increased interest toward the activities proposed by the training. In this sense, motivation and metacognitive aspects—promoting self-awareness, monitoring progress in performance, reducing anxiety, and promoting higher confidence in participant cognitive abilities (Dunlosky et al., 2007)—may have played a role in explaining transfer effects immediately after the training (Carretti, Borella, Zavagnin, & De Beni, 2010). Some training group participants reported that they were stimulated to "make more use of their memory" in everyday life; this might have led to the development of new skills outside the training environment. Several authors have suggested that metacognitive control and self-efficacy might mediate the age effect on memory performance (e.g., Valentijn et al., 2006), and that metacognition is related to executive functions (Shimamura, 2000). A more active engagement in cognitive activities has been shown to be positively related to mental functioning (e.g., Herzog, Hultsch, & Dixon, 1989; Verghese et al., 2003). The opportunity for participants to experience success in recall during training sessions may have had positive influence on their attitude, altering their beliefs about efficacy and control over memory, making them much more flexible in their thinking and enabling them to improve control of performance efficacy. By the same token, a decrease in motivation and in self-initiated efforts to maintain such skills, leading to a production deficit in use of cognitive operation to manage the tasks, might have partly explained the lack of maintenance effects. Interviews to ascertain how participants felt about their cognitive functioning before, immediately after, and at follow-up could have lent support to this interpretation; unfortunately, these were not conducted in the present study, and should be included in future investigations.

Maintenance Effects

To test maintenance of training gains, we presented the same tasks used at pretest to the trained and control groups. We demonstrated an 8-month maintenance effect of WM performance on the Criterion task. This result is in line with previous studies demonstrating long-term maintenance of gains also in older adults on the Criterion task in both WM training (Li et al., 2008) and in dual-task training (e.g., Erickson et al., 2007; Kramer et al., 1995) or updating training (Dahlin et al., 2008).

A novel finding is a selective maintenance that goes beyond that found in the Criterion task: Performance on the Cattell and Pattern Comparison tasks was better at follow-up than at pretest. It is reasonable to suppose that these effects may somehow be related to practice, or to the fact that participants are able to remember items. However, the time lag between pretest and follow-up, and the absence of such maintenance in the control group (which had the same amount of practice and participated in the follow-up), make this improbable. Moreover, no other maintenance effects were found. Transfer effects were not maintained over time for Stroop Color task, but the same was also true—surprisingly—for visuospatial WM (nearest-transfer task) and short-term memory tasks (near transfer). Nonetheless, for most of the tasks, training effects dissipate in time, confirming findings suggesting that unless attempts are made to provide reinforcement to maintain the benefit of an intervention, training gains are lost (see Ball et al., 2002). Booster sessions, in this sense, seem to have positive effects on the maintenance of training benefit (Brehmer, Li, Muller, van Oertzen, & Lindenberger, 2007). Brehmer et al. (2007) showed maintenance of the training benefit through re-presenting mnemonic instructions to reactivate the learned strategies, or more generally the learned attitude. It is possible that repractice on the WM task presented during training before follow-up could have maintained immediate transfer effects.

The particular pattern of training maintenance suggests that the training may have fostered self-initiated successful processing, resulting in more efficient knowledge representation and greater capacity and flexibility, which in turn led to specific maintenance effect. Both processing speed and fluid intelligence are general and basic abilities that determine capacity and are thus strictly interrelated (e.g., Bugg, Zook, DeLosh, Davalos, & Davis, 2006) and also related to WM (e.g., de Ribaupierre & Lecerf, 2006; Salthouse, 1991). It can be postulated that because processing speed is largely considered a basic aspect of cognitive processing that explains the changes in WM performance with aging (Park et al., 2002; Salthouse, 1996), improving WM performance increases the efficiency of cognitive operations fostering ability to move among the basic information processes. The same considerations apply to fluid intelligence performance, because this is strictly related to WM (Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004; for a meta-analysis, see Ackerman, Boyle, & Beier, 2005). In contrast, the other tasks may call upon more task-specific processes and abilities, leading to only transient (immediate) transfer effects. The decrease in gains in the follow-up session for the visuospatial WM task, though unexpected, could depend on the differences in format of information to be processed (verbal vs. numerical and spatial). In fact, although some models conceive WM as a unitary system independently of the material to be processed, some data suggest that the distinction based on format is not irrelevant (see, e.g., Kane et al., 2004; Miyake & Shah, 1999; Park et al., 2002). For tasks involving short-term memory, because here capacity is determined by practiced skills and strategies, the training may have only temporarily altered the domain-specific abilities, after which participants re-engage in automatized skills. For the finding related to inhibition, the lack of maintenance could be ascribed to the choice of task. The Stroop Color task has been shown to tap an inhibition-related function, prepotent response inhibition, and requires the suppression of exogenous, external irrelevant information (Borella et al., 2008; Friedman & Miyake, 2004). According to Friedman and Miyake (2004), this function is indeed considered to be related to the control of information coming from the environment rather than to information coming from memory content; the Stroop Color task should therefore not tax WM resources.

Conclusions

Overall, the findings do not actually disentangle whether the WM training used has led to "formation of a new skill, . . . or whether cognitive mechanisms and capacities of general applicability have been enhanced" (Li et al., 2008, pp. 731–732). Nonetheless, in general the patterns of results we have found inform about the potential for short-term modifiability of WM-related mechanisms and specific maintenance changes at the information-processing level, and certainly suggest some degree of plasticity in older adults. The recent Scaffolding Theory of Aging (Park & Reuter-Lorenz, 2009) proposes that the brain builds scaffolds in response to age-related neural changes. This model suggests that the brain adapts and reorganizes under conditions of new learning and cognitive training, improving ability to scaffold and develop new neural circuitry to compensate for age-related decline (Goh & Park, 2009). It is possible that the training given in our study allowed a general scaffold to be developed, but one that is too fragile to remain erected over time, and with only some of its parts resistant.

One limitation of the present study is the absence of a group of young adults. In fact it was not possible to rule out the group differences (trained vs. control) for transfer effects being due to overestimation, because the potential range of improvement in the older trained group in relation to that in a younger group might have been reduced. Typically, younger adults benefit more from training than do older adults (Dahlin et al., 2008), a pattern that is magnified on extended training (Kliegl, Smith, & Baltes, 1990). Furthermore, plasticity decreases with age (Brehmer et al., 2007): Young-old exhibit larger training-related gains than do old-old (e.g., Verhaeghen, 2000). Our study involves a sample of young-old adults, and would benefit from replication with young adults and old-old adults.

Our overall conclusion is that our results are consistent with a general cognitive flexibility in older adults, as is shown by the overall short-term general transfer effects. Cognitive plasticity can be induced, but only for very general abilities. Determining the nature of cognitive and neural changes of transfer gains would allow for a better understanding of the importance of WM training and also help clarify whether or not there are maintenance effects. A further aspect to consider is the applicability of the intervention gains to everyday life. An unsolved question is whether the benefits, both short-term and long-term, had any impact on the day-to-day lives of the older adults of our study. Despite the maintenance gains being limited to aspects related to the trained process, our findings suggest the modifiability of different cognitive abilities and mechanisms in aging, supporting earlier studies showing the possibility of enhancing WM performance in older adults.

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Received March 24, 2010
Revision received June 12, 2010
Accepted June 17, 2010 ■

Correction to Hutchison, Balota, and Duchek (2010)

In the article "The Utility of Stroop Task Switching as a Marker for Early-Stage Alzheimer's Disease," by Keith A. Hutchison, David A. Balota, and Janet M. Duchek (*Psychology and Aging*, 2010, Vol. 25, No. 3, pp. 545–549), author Janet M. Duchek's name was misspelled as Janet M. Ducheck. The online version has been corrected.

DOI: 10.1037/a0021733