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Training Effects on Dual-Task Performance: Are There Age-Related Differences in Plasticity of Attentional Control?

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A number of studies have suggested that attentional control skills required to perform 2 tasks concurrently become impaired with age (A. A. Hartley, 1992; J. M. McDowd & R. J. Shaw, 2000). A. A. Hartley (2001) recently observed that the age-related differences in dual-task performance were larger when the 2 tasks required similar motor responses. The present study examined the extent to which age-related deficits in dual-task performance or time sharing—in particular, dual-task performance of 2 discrimination tasks with similar motor requirements—can be moderated by training. The results indicate that, even when the 2 tasks required similar motor responses, both older and younger adults could learn to perform the tasks faster and more accurately. Moreover, the improvement in performance generalized to new task combinations involving new stimuli. Therefore, it appears that training can substantially improve dual-task processing skills in older adults.

Keywords: aging, cognitive plasticity, attentional control

How humans concurrently perform multiple tasks has been an important topic in cognitive psychology for several decades, and this knowledge contributes to an understanding of the limits of human cognition (Hazeltine, Teague, & Ivry, 2002). A major source of debate in multiple task studies is whether the execution of two tasks can take place in parallel or whether it requires task-switching strategies (Pashler & Johnston, 1998). Recently, researchers have assessed the effect of extensive practice on dual-task performance to better understand the basic cognitive mechanisms underlying dual-task performance. Some researchers have observed large practice effects on dual-task performance, but without evidence of parallel execution of concurrent tasks (Ruthruff, Johnston & Van Selst, 2001). Others have reported that practice enabled participants to perfectly share their attention between two concurrent tasks (Schumacher et al., 2001). Moreover, researchers have observed substantial interindividual differences in the ability to coordinate two tasks. In fact, Ruthruff, Van Selst, Johnston, and Remington (in press) did show evidence of parallel execution of concurrent tasks (bottleneck bypass) in some participants. Furthermore, a dual-task deficit is also frequently observed in older adults, a group that manifests larger interindividual variability than younger adults. Both types of evidence (practice effects in younger adults and the studies of age-related deficits in dual-task performance) have led some researchers to suggest that dual-task performance is heavily dependent on attentional control strategies, which implies that learning an optimal strategy can improve dual-task performance (Meyer & Kieras, 1997).

Research has also shown that training can substantially reduce older adults' deficits on dual tasks. Kramer, Larish, and Strayer (1995; see also Kramer, Larish, Weber, & Bardell, 1999) developed a computer-based training program in which participants performed a monitoring task (e.g., resetting a moving gauge when it reached a critical point) combined with an alphabet–arithmetic task (e.g., solve K− 3 = ?). Results indicated that older and younger adults could learn to effectively coordinate the performance of two tasks. It is interesting to note that the older adults benefited more than the younger adults from training. Moreover, the skills learned during training transferred to a novel dual-task situation and were retained for up to 2 months (45–60 days). The authors concluded that executive control skills, such as those required to coordinate multiple tasks, could be substantially improved in both older and younger adults. An important aspect of

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Kramer et al.'s study is that a subgroup of older adults, trained in a variable-priority (VP) condition, overcame their initial age-related deficit in dual-task performance to a greater degree than did participants trained in a fixed-priority (FP) condition. In the VP training procedure, participants were required to vary their response priorities between the two tasks, whereas in the more typical FP condition, attention was shared equally between the tasks. The greater improvement obtained under the VP condition suggests that learning to modulate attention may be crucial in the acquisition of task coordination skills.

That dual-task performance is substantially improved through training in older adults is of major importance in the study of age-related deficits in cognition, as older adults' difficulty in performing concurrent tasks has often been reported in the literature (Hartley, 1992; Kramer & Larish, 1996; McDowd & Shaw, 2000). A recent meta-analysis by Verhaeghen, Steitz, Sliwinski, and Cerella (2003) showed evidence of age-related deficiencies in dual-task performance across a variety of dual-task paradigms. However, the tasks Kramer, Larish, and Strayer (1995; Kramer, Larish, et al., 1999) used in their dual-task training studies were complex and involved a variety of perceptual, memory, and motor processes. It thus remains difficult to document which processes improved through training and the means by which older adults were able to improve to a greater extent than younger adults. On the basis of previous studies of attentional control deficits in older adults, one could tentatively suggest that participants in the VP group learned to quickly switch their attention from one task to the other to overcome their initial dual-task deficit. Indeed, age-related differences in performance on switching tasks are well documented in the cognitive aging literature (Meiran, Gotler & Perlman, 2001). Moreover, in a different study, Kramer, Hahn, and Gopher (1999) showed that the age-related deficit in task switching decreased substantially with practice. A switching task never requires one to perform both tasks concurrently and instead consists of rapidly switching from one task to the other. According to the results of Kramer, Hahn, and Gopher (1999), an improved switching skill is one potential way older adults can overcome their difficulty in performing multiple tasks.

Some researchers argue (Pashler & Johnston, 1998) that the most appropriate way to measure the interference between concurrent tasks is to use a combination of simple tasks (e.g., identifying a letter and discriminating between a high and a low tone). In the psychological refractory period (PRP) paradigm, for instance, the delay between the two reaction time (RT) tasks varies, allowing the measurement of the interference between the tasks, which provides a method by which to assess the extent to which the modality of stimulus presentation, the cognitive processes used during task performance, and/or the response processes interfere with one another. In the past few years, an increasing number of studies have used the PRP paradigm to investigate age-related deficits in overlapping task performance (Allen, Lien, Murphy, Sanders, & McCann, 2002; Allen, Smith, Vires-Collins, & Sperry, 1998; Glass et al., 2000; Hartley, 2001; Hartley & Little, 1999). Allen et al. (1998) were the first to report evidence of age-related deficit in time-sharing ability with the PRP paradigm. More recently, Hartley and Little (1999) reported that once they controlled for age-related slowing, older adults, compared with younger adults, showed more slowing of the second task when they had to perform it very close in time after the first task (larger PRP effect), but only when the two tasks required manual responses (see also Hartley, 2001). Hartley and Little concluded that the age-related deficit observed in dual tasks was localized to response generation processes. Glass et al. (2000) also reported larger dual-task costs (greater PRP effects) in older adults but concluded that the observed age-related performance deficit had three sources: general slowing, process-specific slowing, and the use of a more cautious task coordination strategy.

Although the extensive research of Hartley and Little (1999; Hartley, 2001) suggests that older adults often show larger dual-task deficits when both tasks require manual responses, exceptions have been noted (Allen et al., 2002), which suggests that older adults' dual-task deficits in some conditions could be partly explained by age-related differences in task coordination strategies, as Glass et al. (2000) proposed. In fact, Allen et al. (2002) reported an age-equivalent PRP effect using a lexical-decision task, even with two tasks requiring a motor response. This could be explained by the use of an efficient task coordination strategy by older adults. However, an alternative possibility is that the older adults performed the lexical-decision task in an automated fashion.

In a recent study, Maquestiaux, Hartley, and Bertsch (2004) observed that extensive practice did not allow parallel execution of two concurrent tasks in a PRP paradigm. However, it is possible that practice alone did not favor the development of efficient dual-task performance strategies. Indeed, such strategies may only develop when participants are explicitly trained, through individualized adaptive feedback and task prioritization instructions, to concurrently perform multiple tasks (Kramer, Larish, et al., 1999; Kramer et al., 1995).

The present study examines the extent to which training can moderate age-related differences in dual-task performance with two discrimination tasks, as typically used in PRP studies. We are interested in exploring the potential improvement when two concurrent tasks require similar manual responses, a condition that has been identified as problematic for older adults in PRP studies (Hartley, 2001). PRP studies have provided valuable information on older adults' task coordination ability. However, a limitation of the PRP paradigm is that the same task is prioritized throughout an experiment. This task is often referred to as Task 1, as opposed to Task 2, the execution of which should always succeed Task 1. Thus, the fixed task order PRP paradigm might not be ideal for the development of task coordination strategies (Glass et al., 2000). In one study, Schumacher et al. (2001) used an analog of the PRP procedure in which two discrimination tasks were treated as equally important and showed large improvement in dual-task performance. We developed the experimental condition used in the present study on the basis of Schumacher et al.'s (2001) procedure. An interesting aspect of this procedure is the use of three different trial types: when participants performed only one of the two tasks (pure single-task trials), when participants responded to only one task in the dual-task condition (single-task trials mixed with dual-task trials), and when participants actually executed two motor responses to stimuli from two different tasks (dual-task trials). Comparing single-task trials performed in the mixed block with single-task trials performed in the pure block provides a measure of the different processing requirements in the two blocks. Schumacher et al. (2001) observed a difference in RT between the two types of single-task trials, likely because of the requirement to prepare for and maintain multiple task sets in the single-task mixed as compared with the single-task pure condition. In the present article, we refer to this performance cost as a *task-set cost*. The difference in performance between the dual-task trials and the single-task trials in the mixed blocks provides a measure of the processing necessary to perceive multiple stimuli and coordinate the execution of two responses. We refer to the associated RT cost as a *dual-task cost*. Separately estimating task-set and dual-task costs is useful in both deconvolving the age-related differences in dual-task performance and examining the effectiveness of training on age-related differences in preparing for and performing multiple tasks. Indeed, previous research with the task-switching paradigm has shown that older adults have considerable difficulty when they need to be prepared to respond to multiple tasks, as compared with a single task (Kray & Lindenberger, 2000; Mayr, 2001).

In the present study, we used the training procedures Kramer, Larish, et al. (1999) used, with priority instructions (variable vs. fixed) and continuous, individualized adaptive performance feedback. These training procedures are consistent with the principles Schmidt and Bjork (1992) articulated for efficient training and learning: that is, that individuals be encouraged to pursue different ways to perform a complex task (i.e., the prioritization instructions) and that the learners be presented with accurate and timely performance feedback.

As we have briefly discussed, previous studies that have observed superior training effects for VP over FP dual-task training have also done so with relatively complex tasks (Gopher, 1982, 1993; Gopher, Armony & Greenshpan, 2000; Kramer et al., 1995; Kramer, Larish, et al., 1999). In the present study, the tasks and stimulus–response mappings are straightforward and unambiguous. Thus, we do not know whether we will observe VP training advantages with simpler tasks, such as those used here, which may be less amenable to the development of sophisticated task coordination strategies. The individualized, adaptive feedback that we provide in both FP and VP training conditions may be sufficient to promote effective learning. Thus, one might view the present study as establishing a boundary condition (in terms of task complexity) on VP versus FP training differences.

Method

Participants

Thirty-six older adults and 36 younger adults participated in the study. The older adult sample was composed of 17 women and 19 men living in the community, with a mean age of 70 years ($SD = 7$) and 15 ($SD = 3$) years of formal education. The young group was composed of 24 women and 12 men with a mean age of 20 years ($SD = 1.5$) and 14 ($SD = 1.4$) years of formal education. All participants reported good health (on a 5-point scale, the mean score was 4.5 for older adults and 4.6 for younger adults), and none of them had undergone major surgery in the year prior to testing. They also had no history of neurological disease and did not take any medications known to affect cognition. To exclude persons with dementia, we had older participants complete a modified, extended version (Mayeux, Stern, Rosen, & Leventhal, 1981) of the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). The modified MMSE examination did not show any indication of impaired cognitive abilities in the older group (mean score was 56, with a range of 53–57). We screened participants for perceptual impairment by having them complete questionnaires on auditory function and tests for near and far visual acuity. To characterize the participants, we also conducted tests of general mental abilities (Kaufman Brief Intelligence Test), psychomotor speed (box completion and digit copying), perceptual and mental speed (digit symbol, sequential complexity), short-term and working memory (forward, backward, and computation spans), and attention and executive function (Stroop, Trail Making A and B). In each age group, we randomly assigned participants to one of the three conditions (VP or FP training or control). Table 1 presents the participants' performance on the psychometric tests to illustrate the characteristics of the participant populations on different cognitive abilities.

Stimuli and Apparatus

We used a Macintosh iMac for the training and transfer tasks. Participants performed the tasks while comfortably seated in front of the computer in a quiet room. Viewing distance was approximately 45 cm. At this distance, visual stimuli subtended a vertical visual angle of 1.15° and a horizontal visual angle of 0.76°. Letters and numbers appeared in white on a black background in all tasks, with the exception of one transfer task in which the letter *X* alternately appeared in yellow or green. We presented auditory stimuli via headphones equipped with a volume control so that we could adjust volume level if needed, although it was set by default to a constant level.

The training tasks included an auditory discrimination task and a visual identification task, performed both separately and concurrently. The auditory task was to judge whether a tone was low or high in pitch (440 Hz vs. 990 Hz; duration = 250 ms). The visual task was to identify which of two letters (*B* or *C*) was presented on the computer screen. We used two different task combinations as transfer conditions. In the within-modality transfer task, participants performed an auditory discrimination task that involved a new set of sounds, a smooth sound (sine wave 550 Hz) and a rough sound (triangle 550 Hz). Participants performed this task in combination with a visual identification task that involved numbers (*3* and *5*). We also designed a cross-modality transfer in which participants performed two visual identification tasks: pattern discrimination (a solid or a striped square) and number discrimination (*3* and *5*).

Participants started each trial by depressing the space bar. At this time, a fixation point (an asterisk) appeared in the middle of the screen for 500 ms. Then the stimuli for one or both of the tasks were presented either at the same time or with a 200-ms delay between tasks (see below). Participants responded with the index and middle fingers of the right or the left hand, one task per hand. Response hand to task mapping was counterbalanced across participants and remained fixed throughout training. Participants controlled the length of the intertrial interval by triggering the next trial, though a minimum intertrial interval was set at 500 ms.

Procedure

All participants completed a 1-hr neuropsychological testing session (see Table 1), during which they also answered questions on health and demographics. On the 2nd day, they completed a pretraining (described in the *Pretraining Session* section) session that lasted about 1 hr. The participants in the VP and FP groups next engaged in the training protocol, which involved five training sessions (detailed in the *Training Sessions* section), each of which took approximately 1 hr to complete. An additional session was needed for posttesting for all of the participants. The control participants did not take part in the training sessions. However, the same amount of time elapsed between pre- and posttraining sessions for the control and for the VP and FP group participants. The experiment, including pre- and posttesting as well as the five training sessions (for the FP and VP but not the control participants), was completed within a 3-week period.

Pretraining Session

The pretraining session involved three combinations of dual tasks to establish baseline performance for the training and transfer tasks (within-

Table 1
Performance Scores on the Tests Measuring IQ and Other Cognitive Functions

	Older						Younger					
	FP		VP		Control		FP		VP		Control	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
General mental ability												
Kaufman Brief Intelligence Test	115.5	6.1	116.7	9.7	112.3	8.9	111.7	6.4	110.7	5.0	113.8	11.6
Psychomotor and mental speed												
Box completion (correct answers)	39.3	10.3	50.0	13.0	43.5	14.0	56.5	13.7	53.7	13.4	49.8	10.3
Digit copying (correct answers)	60.8	9.8	64.8	13.0	62.2	14.0	75.8	12.0	76.0	9.5	75.0	8.9
Digit symbol (correct answers)	33.9	8.2	33.3	8.3	33.2	7.3	49.9	10.0	48.4	7.2	46.9	7.5
Sequential complexity (correct answers)	33.9	7.9	38.0	8.7	37.7	11.0	42.2	8.8	41.0	11.6	40.7	10.9
Short-term and working memory												
Forward digit span	8.6	2.3	8.6	3.0	8.3	1.9	9.7	2.5	9.1	1.7	10.3	2.0
Backward digit span	6.8	1.9	6.7	1.6	5.9	2.0	9.4	3.8	6.4	1.7	8.5	2.8
Computation span	3.5	1.5	2.6	0.8	2.8	1.0	4.8	2.0	4.2	1.5	4.6	1.6
Attention and executive functions												
Stroop test (correct answers)	33.7	7.5	35.2	7.9	34.9	8.9	52.2	14.0	52.2	11.6	49.3	10.0
Trail Making Test A (time in seconds)	42.3	13.6	40.9	16.3	32.9	9.6	20.7	6.0	21.8	3.1	22.9	7.4
Trail Making Test B (time in seconds)	86.2	22.0	96.0	39.0	76.6	17.0	39.7	9.0	44.1	10.6	51.4	23.7

Note. Scores represent number of correct answers, number of correct sequences (span tests), and time to complete the tasks (in seconds). FP = fixed priority; VP = variable priority.

modality and between-modalities transfer conditions). We counterbalanced the presentation order of the three task combinations across participants, following a Latin square design, and kept it constant for a given participant over the pre- and posttraining sessions.

For a given task combination, participants completed four pure blocks and two mixed blocks of trials, following an ABA design (two pure blocks, followed by two mixed blocks, followed again by two pure blocks). In a pure block, participants performed only one of the two tasks. A pure block contained 20 single-task trials. Presentation order of the two pure blocks, one with the auditory task and one with the visual task, was counterbalanced among sessions but remain fixed within a single session. In the pure block, we asked participants to respond as quickly and accurately as possible. During the mixed blocks, participants performed (a) the two tasks concurrently or (b) just a single task. In a mixed block, a single-task trial differed from a dual-task trial simply in the presentation of one or two stimuli, with no further indication given to the participants. The order of the single- and dual-task trials within the mixed-task blocks was unpredictable. The presentation of single-task trials within mixed blocks offers the advantage of discouraging a strategy of grouping the two responses on dual-task trials and also provides a measure of single-task performance in the mixed-task blocks (in which participants needed to be prepared to perform both of the tasks). The mixed blocks were composed of 40 single-task trials (20 from the visual and 20 from the auditory task) and 40 dual-task trials (10 with each of the four stimulus combinations). During both single-task and mixed blocks in the pre- and posttest sessions, we provided no feedback except for a visual warning (yellow square appearing on the top left portion of the screen with the words “Be careful”) that appeared when participants committed two sequential errors. In the mixed blocks, we instructed participants to complete the two tasks at the same time as fast and accurately as possible.

Training Sessions

In the next five sessions, participants assigned to the VP or FP training group engaged in the training program with the tone discrimination (high and low tone) and the letter discrimination (*B* or *C*) tasks. Control participants only completed pre- and posttest sessions. The training sessions were each composed of pure and mixed blocks of trials presented in an ABA design, similar to the pretraining session (pure–mixed–pure). The training sessions differed from the pre- and posttraining session in several ways. First, in each training session, the participants completed two single-task blocks (20 trials in each block) followed by eight mixed blocks of 80 trials. The session ended with two single-task blocks of 20 trials each. Thus, at the end of each training session, the participants had completed 80 single-task trials in the pure blocks (40 in each task), 320 (40 × 8 blocks) single-task trials in the mixed blocks, and 320 (40 × 8) dual-task trials in the mixed blocks. After five training sessions, the VP and FP participants had completed a total of 400 single-task trials in single-task blocks, 1,600 single-task trials in the mixed-task blocks, and 1,600 dual-task trials in the mixed blocks.

A second important difference between the training and pre-/posttraining sessions is that during the training sessions we provided instructions to induce different prioritization strategies. The training procedure involved two types of between-subjects conditions. A group of participants was trained in the VP condition, and another group completed the FP condition. In the VP condition, the participants were instructed to vary the attentional priority devoted to the two tasks. Moreover, a 200-ms or a 0-ms delay (stimulus-onset asynchrony [SOA]) could separate the onsets of the two stimuli in the dual-task trials. SOA delay was fixed throughout a block of trials. At the beginning of each mixed block, an instruction given to the participants indicated how their effort should be devoted to each task during the block. We used three priority instructions, each of which was presented two times during an experimental session. The three priority instructions were as follows: (a) respond to the tone first, (b) respond as fast as possible on both tasks, and (c) respond to the letter first. For the VP group, each training session was composed of eight mixed blocks that differed by SOA and task priority. Block presentation was randomized within a training session. It is important to emphasize that although priority instructions varied for Blocks 3 to 5 and 8 to 10, in Blocks 6 and 7 we always presented the equal priority instructions and always used a fixed 0-ms SOA. In the FP training condition, we asked the participants to equally emphasize both tasks. That is, in the FP training condition, all mixed-task blocks took the form of Blocks 6 and 7, with an FP instruction and fixed 0-ms SOA. For the purpose of comparing participants' performance in comparable VP and FP conditions, data reported for training sessions involve performance recorded when priority instruction and feedback were equivalent among training groups (Blocks 6 and 7).

Training sessions also differed from pre-/posttraining sessions in that they presented continuous, individualized adaptive feedback. Feedback indicators were presented continuously on a histogram in the top left portion of the screen depicting performance (speed) on the dual-task trials. The histogram contained two bars, one bar for each task. The left bar showed performance in the task performed with the left hand, and the right bar showed the task performed with the right hand. The bars indicated the mean RT for each task in the previous five trials for the dual-task trials only. The bars appeared in red and changed to yellow and then green to indicate progressively better (faster) performance. Figure 1 shows an example of the screen display as it appeared to the participant during a mixed block.

A line on the top of the histogram showed the criterion for good performance, based on a percentile of the response distribution of the single-task trials during the mixed block in each of the sessions. We continuously updated the criterion of good performance on an individual basis as the session evolved and the response distribution of the single-task trials changed. Moreover, the criterion varied according to the priority instructions. If the instruction indicated prioritizing one task, the criterion for good performance on the prioritized task was the 50th percentile (the median) of the RT distribution for that task when it was performed in the previous single-task trials during the whole mixed block. The nonprioritized task was to be performed at the 75th percentile of the RT distribution for that task when it was last performed in single-task trials. When instructions indicated equal emphasis for both tasks, the criterion of good performance was based on the 63rd percentile of the RT distributions of each of the tasks when last performed in the single-mixed trials.

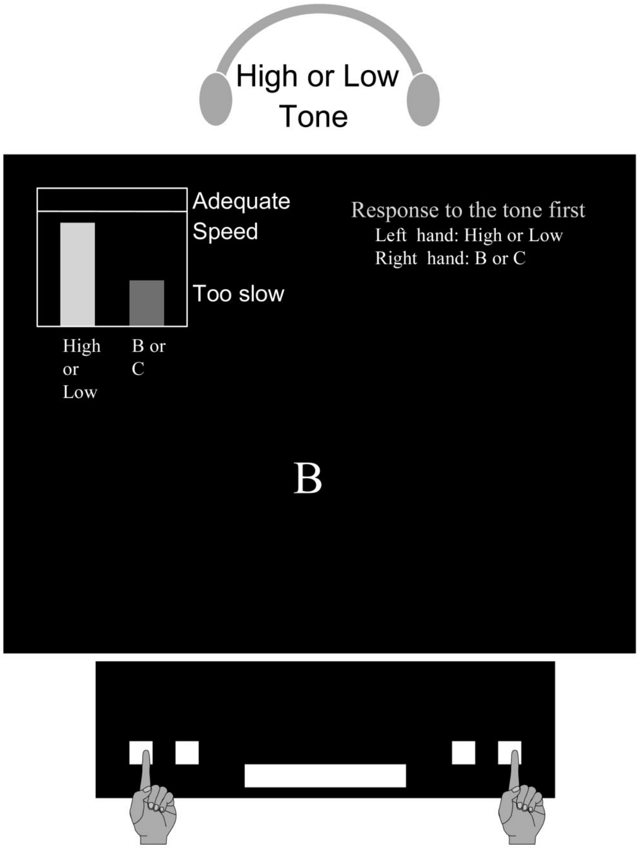

Figure 1. Screen display as it appeared to the participant in mixed blocks during the training sessions. The bars in the histogram show the feedback for response accuracy in the dual-task trials, as a function of a response criterion based on the distribution of the single-task trials of the mixed block.

Posttraining

All participants completed a posttraining session following the fifth training session. In the posttest session, participants completed the three combinations of dual tasks (i.e., the training tasks, within-modality transfer tasks, and cross-modality transfer tasks), following the same order as in the pretraining session.

Results

To characterize our participant groups on their performance on a variety of neuropsychological tests, we performed analyses of variance (ANOVAs) on the data presented in Table 1. The ANOVAs involved age (older and young) and training (FP, VP, and control) as between-subjects factors. We observed age-related differences in favor of younger adults for box completion, $F(1, 66) = 9.0$, $p < .001$; digit copying, $F(1, 66) = 24.0$, $p < .001$; digit symbol substitution tests, $F(1, 66) = 61.0$, $p < .001$; sequential complexity, $F(1, 66) = 4.0$, $p < .05$; forward digit span, $F(1, 66) = 4.8$, $p < .05$; backward digit span, $F(1, 66) = 8.0$, $p < .005$; computation span, $F(1, 66) = 19.0$, $p < .001$; Stroop, $F(1, 66) = 47.0$, $p < .001$; Trail Making Test A, $F(1, 66) = 48.0$, $p < .001$; and Trail Making Test B, $F(1, 66) = 60.0$, $p < .001$. None of these tests showed a difference among training groups or an interaction between age and training, which suggests that the three different groups (FP, VP, and control) were comparable on cognitive abilities.

The dependent variables of interest in the experimental tasks were RT and accuracy. We calculated RT from stimulus presentation to the participant's response. We did not include incorrect responses in the RT analyses, and we also rejected trials if the RT was longer than 3,000 ms or shorter than 100 ms. We calculated accuracy as the percentage of correct responses in each condition. We performed analyses with ANOVAs with two between-subjects factors, age group (older vs. younger) and training group (VP, FP, control), and three within-subject factors, task (auditory and visual), session, and trial type (single pure, single mixed, double mixed). We decomposed significant interactions among these factors with simple effects. However, in the case of a significant interaction with more than two levels of a repeated factor (e.g., five training sessions, three trial types), we used repeated contrasts. Such analyses provide a comparison of RT differences between two consecutive levels of a repeated factor. We performed statistical analyses of the data with SPSS (1997), which provides adjusted alpha levels (Greenhouse–Geisser) for within-subject factors to correct for violations of homogeneity of variance. We report an effect as significant according to the adjusted alpha level when required—that is, when the Mauchly's test of sphericity was significant (SPSS, 1997). We also report effect sizes (eta squared).

In the first set of analyses, we explored participants' performance during the five training sessions, across age and training groups. We performed a second set of analyses to compare pre- versus posttest performance in the training condition as well as the transfer tasks. The same ANOVA model served for the two sets of analyses, with the only difference that the session factor involved two levels in the pre- versus posttest analyses and five levels for training sessions.

Training Sessions

RT analyses. This section summarizes the important findings when we compared participants of the two training groups within the five sessions of training in which they performed the tasks with differential priority instructions (i.e., VP and FP conditions) and received continuously updated, individualized performance feedback. The analyses reported in this section address three main questions. The first question concerns the age-related differences in dual-task performance, which we assessed through age-related differences in trial types. In the presence of a significant effect of trial type or an interaction involving trial type, follow-up analyses indicate whether the effect concerned task-set cost, dual-task cost, or both. The second main question asks whether training type (VP vs. FP) had the same impact on dual-task performance and, if so, whether the effect was equivalent for task-set and dual-task costs. The third question is whether age-related differences emerged relative to the effect of training type and, if so, whether these differences were equivalent across trial types (task-set cost and dual-task cost).

Figure 2a shows RTs as a function of the five training sessions. The graph shows the data collapsed across the two training conditions, VP and FP, as statistically equivalent RT effects were observed in both training groups. In fact, there was no main effect of training condition, $F(1, 44) < 1$, *ns* ($\eta^2 = .00$); no Training × Session interaction, $F(4, 176) < 1$, *ns* ($\eta^2 = .00$); no Age × Training interaction, $F(1, 44) < 1$, *ns* ($\eta^2 = .00$); and no interaction involving training. Data are also collapsed for the visual and the auditory task because of statistically equivalent RT effects in the two tasks: task effect, $F(1, 44) < 1$, *ns* ($\eta^2 = .00$); Task × Session, $F(4, 176) < 1$, *ns* ($\eta^2 = .01$). With regard to age-related differences in dual-task performance, we observed several important results. First, we obtained main effects for age, $F(1, 44) = 39.8$, $p < .001$ ($\eta^2 = .48$). Older adults were slower than younger adults. Moreover, the main effect of trial type reached significance, $F(2, 88) = 276.9$, $p < .001$ ($\eta^2 = .86$). Repeated contrasts indicated that RT was longer in single-task trials performed in the mixed blocks (736 ms), interleaved with dual-task trials, compared with single-task trials performed in the pure blocks (504 ms), $F(1, 44) = 207.8$, $p < .001$ ($\eta^2 = .82$). This indicates significant task-set cost in RT. We also observed that RT was longer in dual-task trials (926 ms) compared with single-task trials within the mixed blocks (736 ms), $F(1, 44) = 270.8$, $p < .001$ ($\eta^2 = .86$). Thus, we also observed significant dual-task cost. An important finding, however, is that we also obtained a significant Age × Trial type interaction, $F(2, 88) = 22.0$, $p < .001$ ($\eta^2 = .34$). Older adults showed both a larger task-set cost than younger adults, $F(1, 44) = 14.2$, $p < .001$ ($\eta^2 = .24$; older = 326 ms, younger = 173 ms), and a larger dual-task cost, $F(1, 44) = 26.0$, $p < .001$ ($\eta^2 = .37$; older = 220 ms, younger = 121 ms). Note that the Age × Trial Type interaction was also significant after we controlled for general slowing, $F(2, 86) = 3.7$, $p < .05$ ($\eta^2 = .08$).[1] However, the task-set cost was statistically equivalent in older and younger adults after we controlled for general slowing, $F(1, 43) = 1.2$, *ns* ($\eta^2 = .03$), whereas dual-task cost remained significantly larger in older compared with younger adults, $F(1, 43) = 6.0$, $p = .02$ ($\eta^2 = .13$).

With regard to the second question of interest, we observed a main effect of training session, $F(4, 176) = 71.1$, $p < .001$ ($\eta^2 = .62$), and repeated contrasts showed that RTs got shorter in each subsequent session (*p*s $< .01$). Moreover, a significant Trial Type × Session interaction, $F(8, 352) = 21.0$, $p < .001$ ($\eta^2 = .32$), indicated that training had a differential impact on the different trial types. Repeated contrasts showed that task-set cost decreased significantly between Sessions 1 and 2, $F(1, 44) = 5.7$, $p < .05$; between Sessions 2 and 3, $F(1, 44) = 4.7$, $p < .05$; and between Sessions 3 and 4, $F(1, 44) = 5.1$, $p < .05$, but did not decrease between the last two sessions. With regard to dual-task cost, we observed significant improvement in performance only between Sessions 1 and 2, $F(1, 44) = 4.5$, $p < .05$, and between Sessions 3 and 4, $F(1, 44) = 11.1$, $p < .05$. It is important to note, however, that there was no evidence of a differential effect of training type (FP vs. VP).

The third question concerns age-related difference in learning, across training and trial type. The Age × Session interaction, $F(4, 176) = 3.1$, $p < .05$ ($\eta^2 = .07$), was significant. However, this interaction failed to reach significance after we controlled for age-related differences in general slowing, $F(4, 172) < 1$. Thus, it appears that the RTs of older and younger adults improved to the same extent as a function of training.

Accuracy analysis. Percentages of correct responses are shown in Figure 2b. We analyzed these data with the same ANOVA model as used in the RT analyses. We obtained main effects for trial type, $F(2, 88) = 28.0$, $p < .001$ ($\eta^2 = .39$), because of a significant task-set cost, $F(1, 44) = 50.0$, $p < .001$ ($\eta^2 = .53$). There was no interaction between trial type and age. However, we observed a significant interaction between age and training type, $F(1, 44) = 5.7$, $p < .05$ ($\eta^2 = .11$). Simple effects further indicated that the FP group of older adults produced a larger percentage of accurate responses (95%) overall, $F(1, 45) = 5.2$, $p = .03$, compared with the VP group (91%). In younger adults, accuracy was equivalent among training groups.

With regard to the effect of training, the main effect of session was significant, $F(4, 176) = 9.0$, $p < .001$ ($\eta^2 = .17$). We found significant improvements in accuracy between the first two sessions, $F(1, 44) = 13.0$, $p < .001$ ($\eta^2 = .23$). The effect of training differed across trial types: Session × Trial Type, $F(8, 352) = 2.3$, $p < .05$ ($\eta^2 = .05$). Simple effects indicated that accuracy increased significantly from the first to the last session in single-task trials, $F(4, 176) = 5.0$, $p < .001$, and dual-task trials, $F(4, 176) = 7.0$, $p < .001$, performed in the mixed block, whereas we observed no significant improvement in the single-task trials performed in the pure blocks, $F(4, 176) = 1.3$.

An important finding relative to the third question, which concerns potential age-related differences in training effects, is that the improvement in accuracy differed among age groups, as indicated

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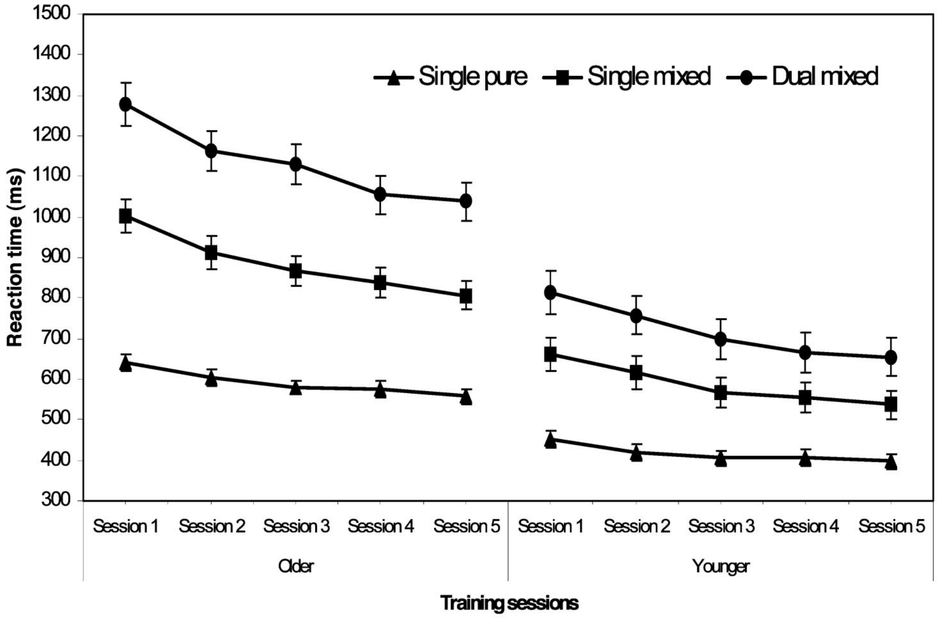
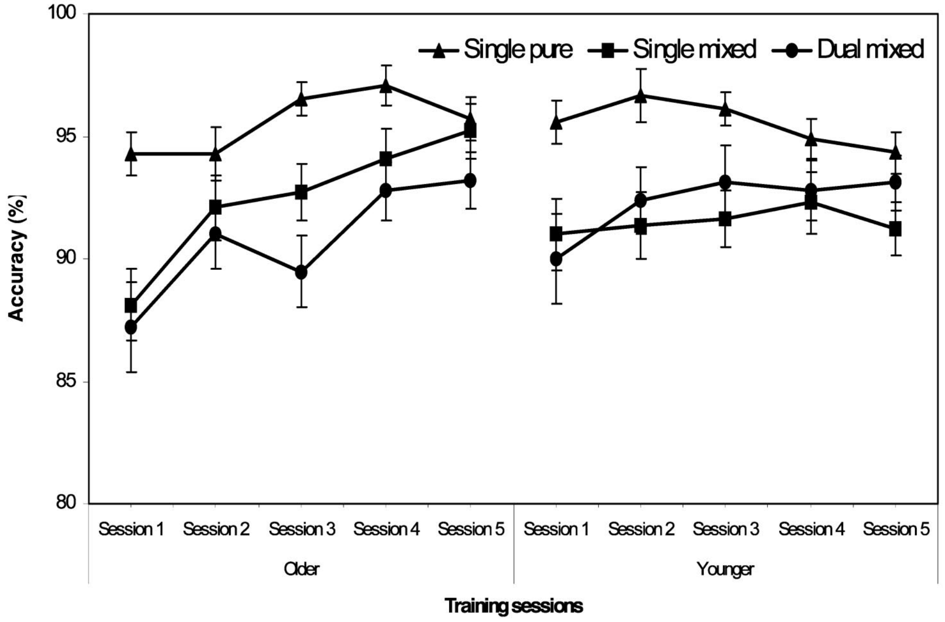
[1] Age-related differences in general slowing are well documented in cognitive aging studies (Madden, 2001). In the present study, we controlled for age-related slowing by conducting analyses of covariance (ANCOVAs) with baseline RT in the single pure trials averaged for the two simple tasks in the first training session. In pre- and posttest analyses, we averaged RT separately for each task combination (training, within modality, and cross-modality). In this study, we consider an interaction involving the age group factor to be significant only if it was also significant in the ANCOVA.



A) Reaction time improvement over five training sessions



B) Percentage of correct responses over five training sessions

Figure 2. (A) Mean reaction time (ms) and (B) percentage of correct responses for older and younger adults in the three trial types (single pure, single mixed, and dual mixed) as a function of the five training sessions.

by a significant Age × Session interaction, $F(4, 176) = 4.7$, $p = .002$ ($\eta^2 = .10$). Simple effects indicated that only older adults showed a significant benefit with training session, $F(4, 184) = 12.0$, $p < .001$, which we did not observe in younger participants, $F(4, 184) = 1.0$, *ns*.

Pre- Versus Posttraining Analyses

RT analysis. Average RTs in the pretraining and posttraining sessions are shown in Figure 3. Here, again, both VP and FP training procedures led to statistically equivalent improvement. Therefore, we pooled the VP and FP participants together to form the *training group*. To quantify the effect of training regimen, we compared the improvement observed in the training group with the pre- and posttest performance of the control group, which did not engage in the dual-task training regimen. We performed three sets of analyses for the training tasks (top panel of Figure 3), the within-modality transfer tasks (middle panel of Figure 3), and the cross-modality transfer tasks (bottom panel of Figure 3), using the same ANOVA model as used for training RT and accuracy data. We emphasize the major findings here to provide answers to three main questions. (a) Were there age-related differences in dual-task performance, and, if so, were the effects equivalent on task-set and dual-task costs? (b) Did training lead to improvement in dual-task performance, and, if so, did age-related differences emerge relative to the effect of training on task-set and dual-task costs? (c) Did any improvement observed during training generalize to the transfer tasks?

Table 2 shows the main results of the ANOVAs performed on RT and accuracy data. One can observe that the results were highly consistent among the three task combinations. With regard to the question of whether there were age-related differences in dual-task performance, one can see that older adults produced longer RTs than younger participants, as indicated by a main effect of age. Respectively for the training task, the within-modality transfer task, and the cross-modality transfer task, mean RTs were 1,026, 1,020 and 960 ms for older adults and 705, 715, and 688 ms for younger adults. The main effect of trial type was also significant. RT was longer in the single-task trials performed in the mixed blocks compared with the pure blocks (significant task-set cost). Moreover, RT was longer in the dual- compared with the single-task trials performed within the mixed blocks (significant dual-task cost). An important finding is that the effect of trial type differed among age groups, as indicated by the Age × Trial Type interaction. In general, both task-set cost and dual-task cost were larger in older compared with younger adults. Respectively for the three task combinations (training, within-modality transfer task, and cross-modality transfer task), task-set costs were 402, 354, and 257 ms in older adults and 251, 233, and 200 ms in younger adults. The comparable dual-task costs were 282, 300, and 393 ms in older adults and 232, 221, and 277 ms in younger adults. We were also interested in whether the Age × Trial Type interaction was due to age-related difference in task-set cost or dual-task cost. We conducted ANOVAs separately on both cost scores. The analyses, also shown in Table 2, indicate larger task-set and dual-task costs for older than for younger adults in the three task combinations. However, after we controlled for general slowing, using baseline RT in single-task pure trials (within each task combination) as a covariate, age-related differences in dual-task cost were no longer significant, whereas the age-related difference in task-set cost remained significant in the training tasks and the within-modality transfer tasks.

The second main question concerns the effect of training on dual-task performance. As one can see in Table 2, the main effect of session was significant. However, the effects of training and session were qualified by a Training × Session × Trial Type interaction, which suggests that the training regimen had a differential impact on dual-task cost and task-set cost. Moreover, in the training task, the four-way Age × Training × Session × Trial Type interaction was significant, which we did not observe in the transfer tasks (see Table 2). We conducted follow-up analyses to these interactions using task-set and dual-task cost. The top panel (training tasks), middle panel (within-modality transfer tasks), and bottom panel (cross-modality transfer tasks) of Figure 4 show the task-set and the dual-task costs for the training and the control groups for older and younger adults.

In the training tasks,[2] the significant Age × Training Group × Session × Trial Type interaction we observed was due to a different pattern of improvement among older and younger adults in dual-task cost. In fact, comparing the training group of older adults with their control participants showed a significant Training × Session × Trial Type interaction, $F(2, 68) = 27.9, p < .001$ ($\eta^2 = .45$). We observed a Training × Session interaction in task-set cost, $F(1, 34) = 22.3, p < .001$ ($\eta^2 = .40$). Simple effects analyses indicated that this was due to a significant decrease of task-set cost in the training group (465 to 240 ms), $F(1, 34) = 52.0, p < .001$ ($\eta^2 = .60$), which we did not observe in the control group (435 to 466 ms), $F(1, 34) < 1$, *ns* ($\eta^2 = .01$). We also observed a Training × Session interaction in dual-task cost, $F(1, 34) = 11.3, p < .01$ ($\eta^2 = .25$), also because of cost reduction in the training group (338 to 211 ms), $F(1, 34) = 30.0, p < .001$ ($\eta^2 = .47$) but not in the control group (287 to 294 ms), $F(1, 34) < 1$, *ns* ($\eta^2 = .00$).

When we compared the improvement observed in the training group with that observed in the control group for younger adults, the results also indicated a Training × Session × Trial Type interaction, $F(2, 68) = 13.2, p < .001$ ($\eta^2 = .28$). As we observed with older adults, the analyses with task-set cost showed a Training × Session interaction, $F(1, 34) = 27.1, p < .001$ ($\eta^2 = .44$), which indicated a larger reduction of task-set cost in the training group (277 to 128 ms), $F(1, 34) = 121.0, p < .001$ ($\eta^2 = .78$), compared with the control group (312 to 286 ms), $F(1, 34) = 2.9$, *ns* ($\eta^2 = .05$). However, contrary to our findings for older adults, for younger adults the reduction in dual-task cost was equivalent between the training (259 to 119 ms) and control (320 to 230 ms) groups, $F(1, 34) = 2.2$, *ns* ($\eta^2 = .06$). Even though improvement was larger in the training group, $F(1, 34) = 51.0, p < .001$ ($\eta^2 = .60$), we observed unexpected improvement in control participants, $F(1, 34) = 10.0, p < .01$ ($\eta^2 = .24$). Hence, these data suggest that older adults, compared with their controls, benefited to a greater degree than younger adults from dual-task training.

The third question of interest asks whether training effects generalized to the within-modality transfer tasks and the cross-modality transfer tasks.[3] In the two task combinations, the effect of training was qualified by a significant three-way Training Group × Session × Trial Type interaction. In the within-modality transfer tasks, further analyses (see Table 2) showed a significant Training × Session interaction in both task-set cost and dual-task cost because of a significant reduction in the training group for task-set cost (339 to 209 ms), $F(1, 70) = 51.0, p < .001$ ($\eta^2 =$

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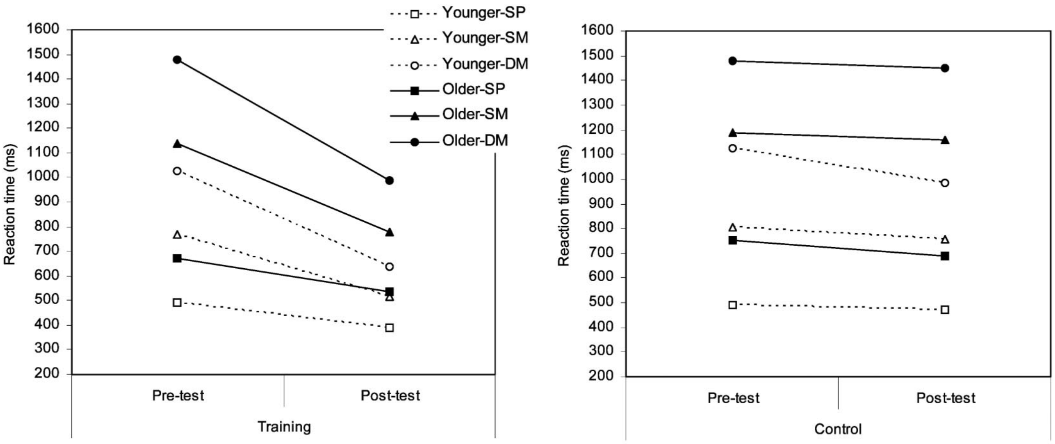
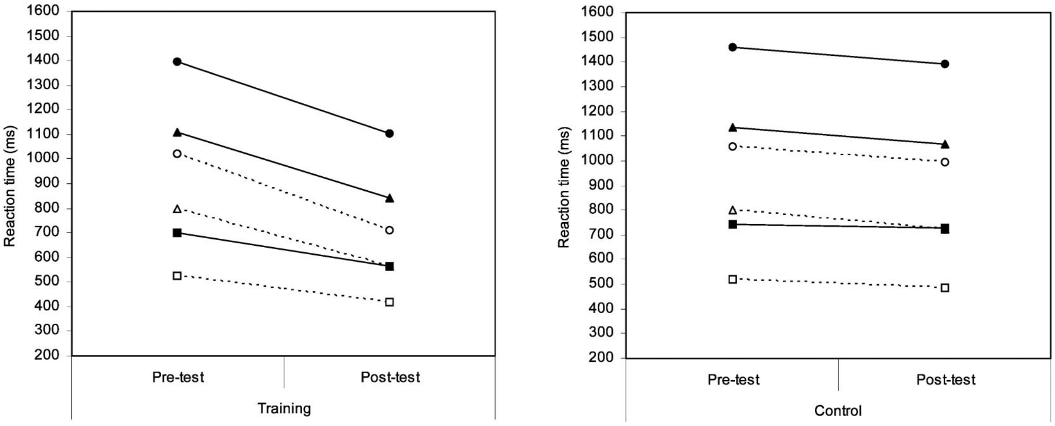
[2] In the training tasks, the results also indicated a significant Task × Session × Trial Type interaction, $F(2, 136) = 3.7, p < .05$ ($\eta^2 = .05$). Analyses with the cost scores further showed that dual-task costs decreased from pretest to posttest to a greater extent in the tone discrimination task (311 to 172 ms) compared with the letter discrimination task (289 to 224 ms), $F(1, 68) = 7.0, p < .01$, whereas improvement in task-set cost was equivalent in the two tasks. It is important to note that this did not differ among training groups or age groups.

[3] RT analyses in the cross-modality transfer tasks showed a significant Training Group × Task interaction, $F(1, 68) = 7.1, p < .01$ ($\eta^2 = .10$). Simple effects showed that in the training group, RT was shorter in the number discrimination task (797 ms) compared with the pattern discrimination task (835 ms), which we did not observe in the control groups. It is important to note that this effect did not interact with training session or age.

Training tasks tasks



Within-modality transfer tasks



Cross-modality transfer tasks

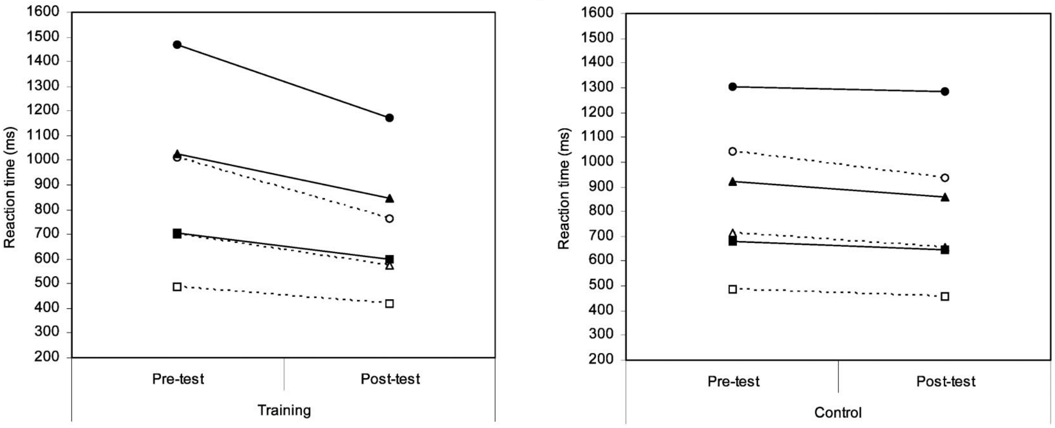


Figure 3. Mean reaction time (ms) for older and younger adults in the three trial types (single pure [SP], single mixed [SM], and dual mixed [DM]), as a function of pretraining and posttraining session, for the training tasks (upper panel), the within-modality transfer tasks (middle panel), and the cross-modality transfer tasks (lower panel).

Table 2
Results of the Analyses of Variance Performed on Reaction Time and Accuracy for the Three Task Combinations Used in the Pretraining and Posttraining Sessions

	Training task				*Within-modality transfer task*				*Cross-modality transfer task*			
Task combination	*df*	*F*	$p <$	η^2	*df*	*F*	$p <$	η^2	*df*	*F*	$p <$	η^2
					Reaction time (ms)							
Age group	1, 68	59.8	.001	.47	1, 68	58.2	.001	.46	1, 68	43.9	.001	.39
Training group	1, 68	15.1	.001	.18	1, 68	7.5	.01	.10	1, 68	0.2	*ns*	.00
Session	1, 68	141.0	.001	.68	1, 68	76.7	.001	.53	1, 68	65.6	.001	.49
Trial types	2, 136	709.0	.001	.91	2, 136	663.0	.001	.91	2, 136	570.9	.001	.89
Age × Trial Type	2, 136	22.7	.001	.25	2, 136	22.0	.001**	.24	2, 136	13.8	.001	.17
Age difference on task-set cost	1, 68	28.1	.001*	.29	1, 68	19.3	.001**	.22	1, 68	4.8	.05	.07
Age difference on dual-task cost	1, 68	5.2	.05	.07	1, 68	13.0	.001	.16	1, 68	20.5	.001	.23
Training × Session × Trial Type	2, 136	41.0	.001**	.38	2, 136	9.8	.001**	.13	2, 136	11.9	.001**	.15
Training × Session in task-set cost	1, 68	41.0	.001**	.38	1, 68	7.7	.01**	.10	1, 68	2.7	*ns*	.04
Training × Session in dual-task cost	1, 68	12.3	.001**	.15	1, 68	4.0	.05*	.06	1, 68	14.5	.001**	.18
Age × Training × Session × Trial Type	2, 136	6.0	.01**	.08	2, 136	0.9	*ns*	.01	2, 136	1.3	*ns*	.02
					Accuracy (%)							
Age group	1, 68	6.8	.01	.09	1, 68	< 1.0	*ns*	.01	1, 68	2.6	*ns*	.04
Training group	1, 68	< 1.0	*ns*	.00	1, 68	< 1.0	*ns*	.00	1, 68	5.2	.05	.07
Session	1, 68	12.2	.001	.15	1, 68	4.8	.05	.07	1, 68	<1.0	*ns*	.01
Trial type	2, 136	14.6	.001	.18	2, 136	1.4	*ns*	.02	2, 136	5.6	.01	.08
Age × Session	1, 68	6.9	.01	.09	1, 68	< 1.0	*ns*	.01	1, 68	3.6	.06	.05
Age × Training × Session	1, 68	4.6	.05	.06	1, 68	11.0	.001	.14	1, 68	<1.0	*ns*	.01

Note. To control for the general slowing effect, we performed analysis of covariance using mean reaction time in single-pure trials in each task combinations as covariate.
* $p < .05$. ** $p < .01$.

.42), and dual-task cost (257 to 204 ms), $F(1, 70) = 11.0$, $p < .001$ ($\eta^2 = .04$), which we did not observe in the control group: task-set cost (333 to 292 ms), $F(1, 70) = 2.5$, *ns* ($\eta^2 = .04$); dual-task cost (288 to 294 ms), $F(1, 70) < 1$, *ns* ($\eta^2 = .04$). We observed the same pattern of results in the cross-modality transfer tasks, which also showed a Training × Session × Trial Type interaction. Although analyses with task-set cost did not show a Training × Session interaction (see Table 2), simple effects showed significant improvement in task-set cost in the training group (266 to 202 ms), $F(1, 70) = 25.0$, $p < .001$ ($\eta^2 = .27$), but not in the control group (236 to 208 ms), $F(1, 70) = 2.4$, *ns* ($\eta^2 = .03$). The Training × Session interaction was significant for dual-task cost, as shown in Table 2. This was due to a significant decrease in dual-task cost in the training group (376 to 259 ms), $F(1, 70) = 43.0$, $p < .001$ ($\eta^2 = .38$), which we did not observe in the control group (354 to 354 ms), $F(1, 70) < 1$, *ns* ($\eta^2 = .00$).

Accuracy analysis. We analyzed the percentage of correct responses with a statistical model similar to the one used with RT. Mean accuracy data obtained in pretraining and posttraining sessions are shown in Figure 5 for the training tasks (top panel), the within-modality transfer tasks (middle panel), and the cross-modality transfer tasks (bottom panel). The main findings with regard to age, trial type, and training effects as well as interactions involving these factors are summarized in Table 2. A general finding is that training led to larger improvement in accuracy for older compared with younger adults. In fact, we observed a significant Age × Training × Session interaction in both the training tasks[4] and the within-modality transfer tasks.[5] We performed further analyses comparing the two training groups of older and younger adults, and these analyses showed a significant Age × Session interaction in the training tasks, $F(1, 46) = 14.8$, $p < .001$ ($\eta^2 = .24$), and the within-modality transfer tasks, $F(1, 46) = 11.6$, $p < .001$ ($\eta^2 = .20$), as a result of a significant improvement in response accuracy for older adults: 87% to 96% in training tasks, $F(1, 46) = 27.0$, $p < .001$ ($\eta^2 = .37$); and 90% to 94% in within-modality transfer tasks, $F(1, 46) = 16.0$, $p < .001$ ($\eta^2 = .25$). The percentage of correct responses did not change with session in younger adults: training tasks, 95% to 94%, $F(1, 46) < 1$, *ns* ($\eta^2 = .00$); within-modality transfer tasks, 94% to 93%, $F(1, 46) < 1$, *ns* ($\eta^2 = .02$. In the control groups, the Age × Session interaction did not reach significance—training tasks, $F(1, 22) < 1$, *ns* ($\eta^2 = .01$); within-modality transfer tasks; $F(1, 22) = 3.3$, *ns* ($\eta^2 = .13$)—which suggests no differential changes in accuracy from pretraining to posttraining. For control participants, accuracy

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[4] Accuracy analyses with the training tasks also showed two significant interactions effects, Age × Task × Session × Trial Type, $F(2, 136) = 3.0$, $p = .05$ ($\eta^2 = .04$), and Training × Task × Session × Trial Type, $F(2, 136) = 3.3$, $p < .05$ ($\eta^2 = .05$), which suggests that training effect and age-related difference in accuracy independently varied between the visual and the auditory tasks. However, because the Age × Training interaction factor was not involved in these higher order interactions, we do not consider them relevant for the purpose of this study.

[5] Accuracy analyses in the within-modality transfer tasks showed a significant Age × Task interaction, $F(2, 68) = 5.0$, $p < .05$ ($\eta^2 = .07$), because of a larger discrepancy in accuracy between the auditory and the visual tasks in younger adults, which we did not observe in older adults. It is important to note that these effects did not change from pretest to posttest.

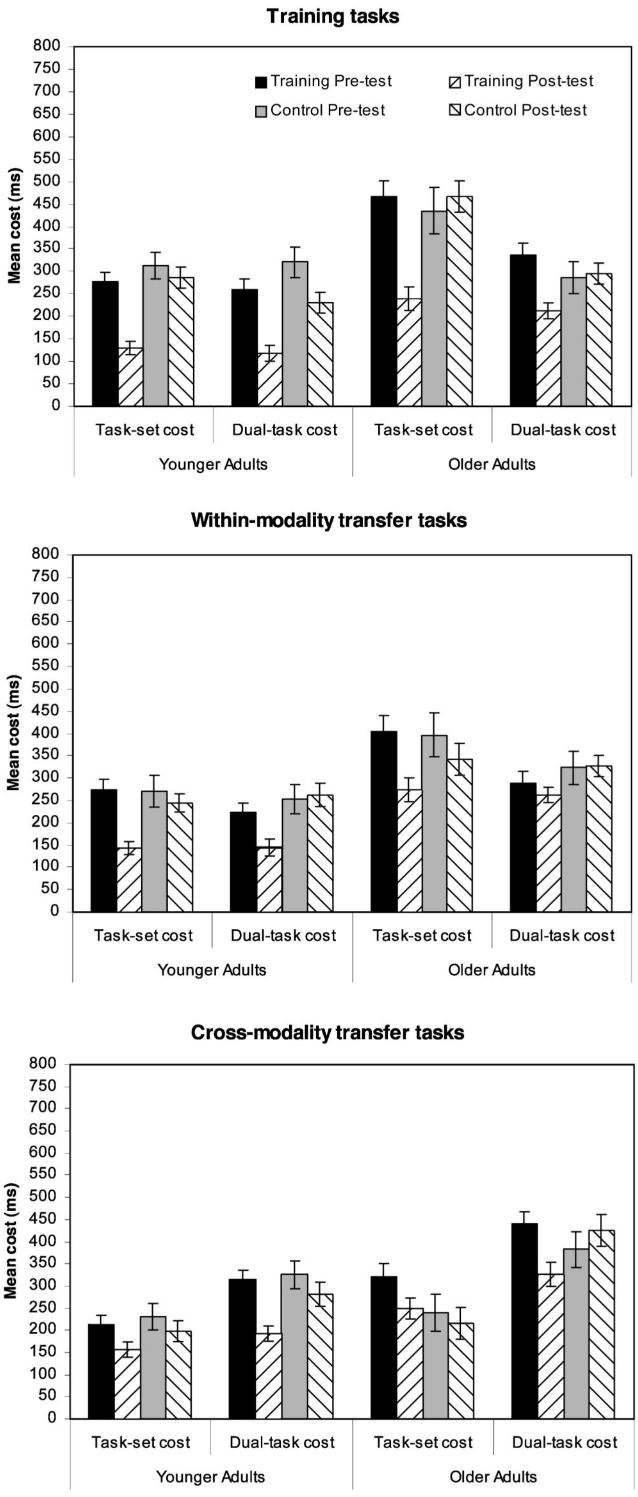


Figure 4. Mean task-set cost and dual-task cost in older and younger adults at pretraining and posttraining session for the training tasks (upper panel), the within-modality transfer tasks (middle panel), and the cross-modality transfer tasks (lower panel).

varied from 90% to 93% and from 93% to 95%, respectively, for older and younger adults in the training tasks and from 95% to 95% and from 91% to 94%, respectively, for older and younger adults in within-modality transfer tasks.

The cross-modality transfer task did not show a three-way Age × Training × Session interaction (see Table 2), as we observed in the training and the within-modality transfer tasks. However, older adults still showed a larger improvement in accuracy (96%–97%) in the cross-modality transfer task compared with younger adults (95%–95%), though the Age × Session interaction also failed to reach a significant level.

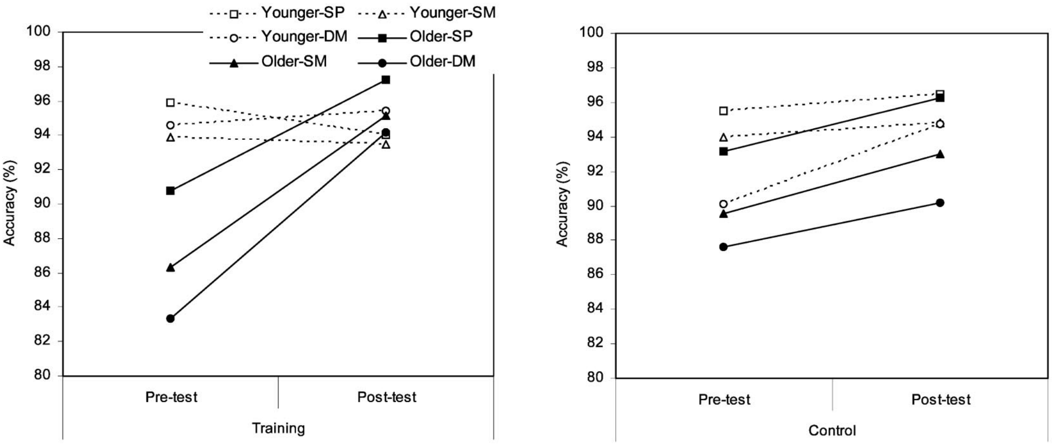
Discussion

The goal of the present study is to assess the extent to which training can improve dual-task performance in older and younger adults. We trained participants to perform two discrimination tasks concurrently, a tone and a letter discrimination task, both requiring a manual response. We provided continuous, individualized adaptive feedback and priority instructions on a computer screen during the training sessions. We assessed performance improvement at pretraining and posttraining sessions in the training tasks. We also assessed within-modality transfer and cross-modality transfer using new sets of stimuli in pretraining and posttraining sessions. We used the transfer tasks to assess whether acquired task coordination skills generalized to untrained stimuli, within and between modalities. Moreover, we explored whether training would lead to a significant improvement in three different trial types: pure single-task trials, single-task trials mixed with dual-task trials, and dual-task trials. Comparing performance in these three types of trials allowed us to assess improvement in task-set cost (RT in mixed single-task trials − RT in pure single-task trials) and dual-task cost (RT in dual-task-trials − RT in mixed single-task trials).

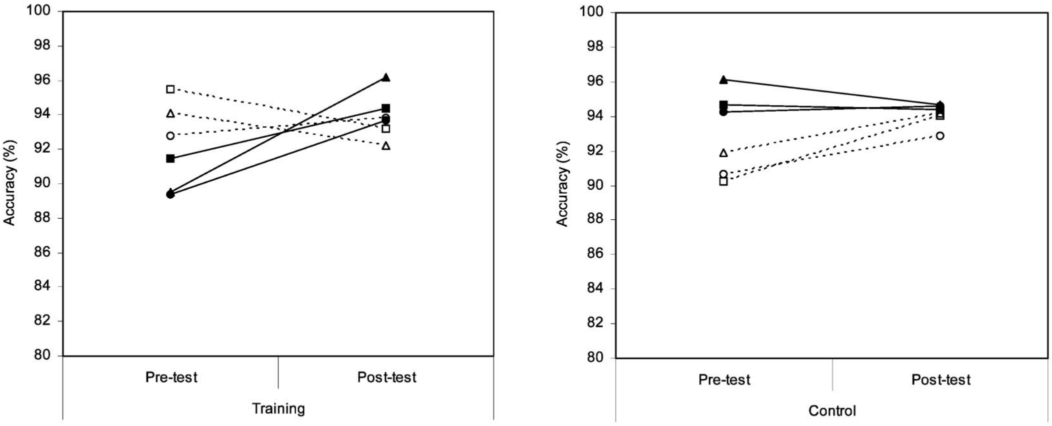
The data obtained in the present study address three main questions: (a) Is there a robust age-related difference in dual-task performance? (b) Does training type (VP vs. FP) have a differential influence on reductions in task-set and dual-task costs, and are these training effects similar for younger and older adults? (c) Finally, do training effects transfer to different stimuli, within and across modalities?

With regard to the first question, we observed larger task-set and dual-task costs for older than for younger adults across the training and transfer tasks used in the current study. We found age-related differences in dual-task and task-set costs in all task combinations. However, controlling for general slowing eliminated dual-task cost but not task-set cost in pre- and posttraining sessions, whereas during the five training sessions, age-related differences in task-set cost but not dual-task cost were eliminated after we controlled for speed. With regard to the second question, training led to reductions in RT for each of the three trial types and for the task-set and dual-task costs for the training group but not for the control group. However, the type of training (FP or VP) was not an important determinant of the magnitude of the training benefit. Younger and older adults showed equivalent reductions in RT, whereas the older adults showed larger increases in accuracy than younger adults as a function of training. Finally, with regard to the third question, we observed transfer effects to both within- and between-modalities novel stimuli for the participants who served in the two training groups.

Training tasks tasks



Within-modality transfer tasks



Cross-modality transfer tasks

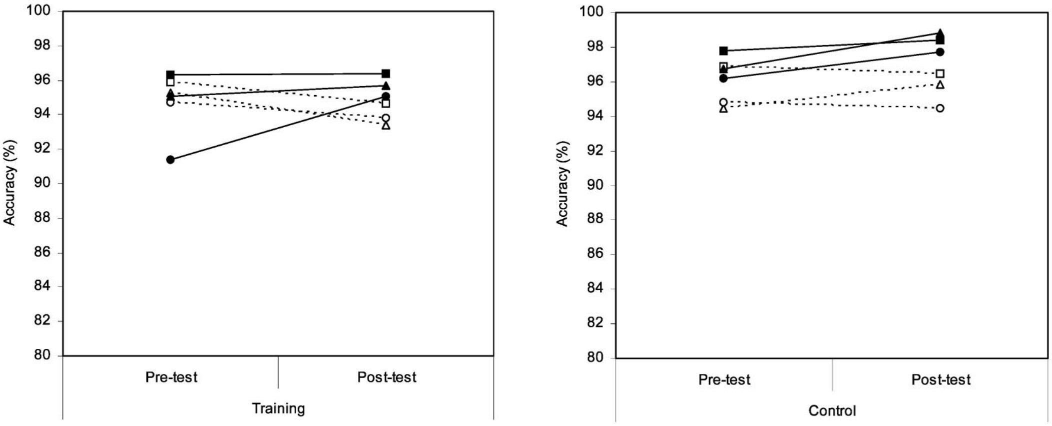


Figure 5. Percentage of correct responses produced by older and younger adults in the three trial types (single pure [SP], single mixed [SM], and dual mixed [DM]), as a function of pretraining and posttraining session, for the training tasks (upper panel), the within-modality transfer tasks (middle panel), and the cross-modality transfer tasks (lower panel).

A number of previous studies that have examined potential age-related differences in divided attention have found evidence for deficits for older adults (Hartley, 1992; McDowd & Shaw, 2000; see Verhaeghen et al., 2003, for a meta-analysis). A novel contribution of the present study is the dissociation between task-set and dual-task costs attributable to the coordination of multiple tasks. What our data suggest is that task-set costs may be more of a problem for older adults than dual-task costs—and hence it may be important to separately examine these two types of performance costs in future aging studies. The cost induced by the task context has also been identified as a problem for older adults in task-switching studies (see Mayr, 2001). In a typical task-switching paradigm, participants complete two tasks, in separate trial blocks (as in the pure block of the present study) and in switch blocks, in which, after a variable number of trials in one task, they must rapidly switch to the other task. Although early task-switching studies with older adults suggested that age impairs the ability to rapidly switch between tasks, incurring a specific switch cost (longer RT on switch vs. nonswitch trials in the switch block), the age-related difference appears to be minimal if participants have enough time to prepare for the switch, if working memory demand is low, or if sufficient practice has been provided (Kramer, Hahn, & Gopher, 1999; Meiran et al., 2001). However, researchers have repeatedly observed age-related RT differences when they have compared performance between switch blocks and pure task trial blocks (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000; Mayr, 2001). Thus, in both dual-task and task-switching paradigms, older adults appear to have more difficulty preparing for multiple tasks than they do either switching between two tasks or performing multiple tasks concurrently.

An important issue in cognitive training is whether the benefit of training generalizes to different stimuli and tasks (Kramer & Willis, 2003; Schmidt & Bjork, 1992). In the present study, we assessed transfer of task coordination skills in two conditions: within-modality and cross-modality transfer tasks. We introduced a new stimulus set for both the visual and the auditory discrimination tasks in the within-modality transfer condition. Performance improvements for the within-modality transfer task, when we compared the control group with the two (FP and VP) training groups, were quite similar to improvements observed for the trained stimuli. Both task-set and dual-task performance costs were reduced for both the younger and the older training participants but not for the control group participants when we compared performance in the pre- and posttraining assessment sessions. Furthermore, transfer benefits were similar for the two age groups, with the exception of accuracy, for which the older training group participants showed larger improvements than the young adults.

In the cross-modality transfer condition, participants concurrently performed two different visual discrimination tasks with stimuli that were not used in the training tasks. The results were similar to those obtained for the within-modality transfer condition. Both young and older adults in the training groups showed significant reductions in task-set and dual-task costs in the cross-modality transfer condition. We did not observe such improvements for the control participants. The transfer effects are important in that they suggest that dual-task skills improved through training and that learning, in the present study, entailed more than specific stimulus–response mappings (Batsakes & Fisk, 2000; Ho & Scialfa, 2002). That is, participants in the VP and FP training conditions demonstrated decreases in task-set and dual-task costs beyond the stimuli and, in the case of the cross-modality transfer condition, beyond the modality of stimulus presentation on which they were trained. Thus, the transfer data suggest that participants learned a somewhat generalizable set of skills that entailed the ability to prepare to perform multiple tasks as well as the ability to perform multiple tasks concurrently. Whether such skills generalize beyond two-choice discrimination tasks is an important question for future research. Clearly, many previous studies either have found very narrow transfer or have failed to observe any transfer from one task to another (e.g., Ball et al., 2002). However, other studies in the literature suggest transfer of training, at least in dual-task paradigms, between quite different sets of stimuli and tasks (Kramer et al., 1995; Kramer, Larish, et al., 1999).

The transfer effects are also notable in that the magnitude of transfer benefits was at least as large for older as for younger adults and, in the case of the accuracy measure, larger for the older than for the younger adult participants. This is quite an interesting finding, especially in light of the often reported observation of reduced training benefits for older adults (Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995). However, it is important to note that in most previous studies of potential age-related differences in learning, participants were asked to practice tasks without the benefit of individualized adaptive feedback, which was available for the training participants in the present study. Therefore, an important topic for future research is a systematic study of the potential efficacy, for both younger and older adults, of different training protocols for enhancing learning and transfer.

In an effort to further evaluate the robustness of training and transfer effects, we brought back as many participants as possible 1 month after the conclusion of the study to evaluate retention. Unfortunately, given the number of participants who were unable to return for follow-up testing, one must view these results with caution. Fourteen older and 18 younger adults across the control and two training groups participated in the retention session. We found that participants largely retained training (and transfer) gains across the 1-month period and that retention was similar for young and older adults. Thus, although the relatively small number of participants in the retention session precludes strong conclusions, these data do suggest that learning and transfer effects were relatively robust. Of course, additional studies are needed to further examine potential age-related differences in retention of acquired skills.

Finally, some discussion is warranted concerning the similar training effects observed for FP and VP training protocols in the present study. As discussed in the introduction, previous studies have found that VP training resulted in more substantial learning and transfer effects than FP training for both younger and older adults (Kramer et al., 1995, Kramer, Larish, et al., 1999). Researchers have attributed these differential training protocol effects to the requirement to constantly shift processing priorities between two tasks in the VP but not in the FP training condition (in which both tasks are treated with equal priority).

Why, then, did we not observe superior training and transfer benefits for the VP training strategy in the present study? One distinct possibility concerns the nature of the tasks used in the different studies. In the present study, participants performed two-choice auditory and visual discrimination tasks in which stimuli were presented discretely and at fixed temporal intervals. In previous studies, in which VP benefits were larger than those observed for FP training, participants performed a combination of self-paced and force-paced tasks as well as tasks with more continuous processing requirements (e.g., two-dimensional manual tracking, monitoring and resetting pointers on up to six separate gauges). Given these differences in the nature of the tasks across studies, it could be the case that varying priorities among different tasks, as is the case with the VP training protocol, is most beneficial in settings in which there are many degrees of freedom in how two tasks might be coordinated. Clearly, the coordinative possibilities are fewer with two tasks in which stimuli are presented discretely, responses are discretely evoked, and timing is fixed than for tasks that are self-paced and continuous in nature. Another possibility is that the lack of VP and FP training effects was the result of the considerable amount of task coordination practice that participants received in the mixed blocks switching between tasks and single- and dual-task conditions. These executive control challenges, coupled with the relatively simple nature of the stimuli and responses, might have been sufficient to engender the training effects that were specific to VP training with more complex tasks. Future studies are necessary to further examine the relation between training flexible prioritization of tasks and task characteristics.

In summary, the present study is important in suggesting that even under conditions in which older adults have previously been shown to have the most difficulty in performing two discrimination tasks—that is, when both tasks require manual responses (Hartley, 2001; Hartley & Little, 1999)—training has substantial positive benefits on performance and learning. Indeed, training showed substantial and age-equivalent training and transfer benefits for both the ability to maintain multiple task sets and the ability to perform multiple tasks concurrently. Such effects suggest that even older adults possess sufficient plasticity to learn new tasks and skills.

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