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TRANSFER EFFECTS IN TASK-SET COST AND DUAL-TASK COST AFTER DUAL-TASK TRAINING IN OLDER AND YOUNGER ADULTS: FURTHER EVIDENCE FOR COGNITIVE PLASTICITY IN ATTENTIONAL CONTROL IN LATE ADULTHOOD

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Abstract

Older adults' difficulties in performing two tasks concurrently have been well documented (Kramer & Madden, 2008). It has been observed that the age-related differences in dual-task performance are larger when the two tasks require similar motor responses (Hartley, 2001) and that in some conditions older adults also show greater susceptibility than younger adults to input interference (Hein & Schubert, 2004). The authors recently observed that even when the two tasks require motor responses, both older and younger adults can learn to perform a visual discrimination task and an auditory discrimination task faster and more accurately (Bherer et al., 2005). In the present study, the authors extended this finding to a dual-task condition that involves two visual tasks requiring two motor responses. Older and younger adults completed a dual-task training program in which continuous individualized adaptive feedback was provided to enhance performance. The results indicate that, even with similar motor responses and two visual stimuli, both older and younger adults showed substantial gains in performance after training and that the improvement generalized to new task combinations involving new stimuli. These results suggest that dual-task skills can be substantially improved in older adults and that cognitive plasticity in attentional control is still possible in old age.

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In the past few years, many studies have examined the effect of practice on dual-task performance in order 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 enables participants to perfectly share their attention between two concurrent tasks (Schumacher et al., 2001). Moreover, substantial interindividual differences in the ability to coordinate two tasks have been observed. In fact, Ruthruff, Van Selst, Johnston, and Remington (2006) showed evidence of parallel execution of concurrent task (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 age-related deficits in dual-task performance, suggest that dual-task performance relies upon attentional control strategies. This implies that training and learning an optimal strategy could help to improve dual-task performance (Meyer & Kieras, 1997).

Several studies have shown that indeed dual-task training can lead to substantially enhanced performance in both younger and older adults. Kramer, Larish, and Strayer (1995; see also Kramer, Larish, Weber, & Bardell, 1999) used an adaptive, individualized 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 can learn to effectively coordinate the performance of two tasks. Interestingly, 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 to 60 days). An important aspect of the training procedures utilized by Kramer, Larish, et al. (1999) is the continuous, individualized adaptive performance feedback provided to the participants during the training sessions as well as the variable-priority (VP) training condition in which subjects were required to vary their response priorities between the two tasks by prioritizing one task over the other. In Kramer, Larish et al.’s study, VP training produced a greater improvement in dual-task performance than fixed-priority training (FP) in which participants are instructed to equally share attention between two tasks. The training procedures used by Kramer, Larish, et al. are consistent with the principles articulated by Schmidt and Bjork (1992) 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. However, the superiority of training and transfer effects for VP compared to FP procedure in dual-task training has been observed with relatively complex tasks (Kramer, Larish et al., 1995, 1999), which limits the interpretation in terms of the processes involved in this phenomenon.

Results from the studies reported so far suggest that executive control skills, such as those required to coordinate multiple tasks, could be substantially improved in both older and younger adults. Improvement in dual-task performance in older adults is of major importance in the study of age-related cognitive decline because older adults’ deficit in dual-task performance is well documented (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 paradigms. However, many dual-task paradigms are complex and involved a variety of perceptual, memory, and motor processes, and do not allow the localization of the source of improvement in dual-task performance. In fact, improvement can be due to enhanced ability to resolve interference between upcoming stimuli, increased ability to synchronize concurrent output, or to improvement in task switching abilities. Indeed, Kramer, Hahn, and Gopher (1999) have shown that the age-related deficit in task switching, well documented in the cognitive aging literature (Meiran, Gotler, & Perlman, 2001), decreases substantially with practice. A switching task differs from a dual-task situation, as it never requires performing both tasks concurrently and instead consists of rapidly switching from one task to the other.

In an effort to better isolate interference between concurrent tasks, researchers have often used a combination of simple tasks (e.g., identifying a letter and discriminating between a high or low tone), such as in the Psychological Refractory Period (PRP) paradigm. In a typical PRP task, the delay between the two reaction time tasks varies, which provides a method by which to assess the extent to which the modality of stimulus presentation (input interference), the cognitive processes employed during task performance (central interference), and/or the response processes (output interference) interfere with one another. Over the past few years, PRP studies with older adults have contributed to understand the 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 deficits in time-sharing ability with the PRP paradigm. Hartley and Little (1999) reported that after controlling for general slowing, older adults show larger deficits compared to younger adults only when the two tasks required manual responses (see also Hartley, 2001) and concluded that the age-related deficit observed in dual-tasks is localized to response generation processes. More recently, Hein and Schubert (2004) also reported increased susceptibility to *input* interference in dual-tasks in older adults and concluded that parallel processing at the input stage requires cognitive control and should also be considered as a source of age-related deficits in dual-task performance. 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 has three sources: general slowing, process-specific slowing, and the use of a more cautious task-coordination strategy by older adults. Note, however, that 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 in conditions in which one of the two tasks involved processes that operate in an automated fashion. In a more recent study, Lien et al. (2006) reported evidence of improved cognitive processes with age in a PRP paradigm in which task 2 is a lexical decision task. The authors hypothesized that greater experience with lexical processing confers an advantage to older adults compared to younger adults when it comes to performing a lexical decision task in parallel with another task.

The studies reported above thus suggest that older adults' deficit in dual-task performance as observed with the PRP paradigm, or combination of simple and well-controlled tasks, could partly be due to greater sensitivity of older adults to input and output interference as well as less efficient coordination strategies (Glass et al., 2000; Hein & Schubert, 2004).

An important question is whether it is possible to improve older adults' dual-task performance skills through training in the PRP paradigm as has been observed with more complex tasks (see Kramer et al., 1995, 1999). Maquestiaux, Bertsch, and Hartley (2004) found 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 subjects are explicitly trained, through individualized adaptive feedback and task prioritization instructions, to concurrently perform multiple tasks (Kramer et al., 1995, 1999).

In a recent study (Bherer et al., 2005), we examined the extent to which dual-task performance with two discrimination tasks, as typically used in PRP studies, can be enhanced in older adults. We were interested in exploring the potential improvement when two concurrent tasks require similar manual responses but different input modalities, a condition that has been identified as problematic for older adults in PRP studies (Hartley, 2001). We used a paradigm similar to that used by Schumacher et al. (2001), in which dual-task performance is assessed when two discrimination tasks are treated as equally important instead of treating the tasks in a sequential order as in a typical PRP paradigm. Treating the tasks as equally important is thought to favor parallel processing of the two tasks. In our version of the task, participants were also provided with real-time individualized feedback (independently for each task) in the form of a graph presented on the computer screen, as such feedback appeared important in previous dual-task training studies.

Moreover, consistent with the principles of Schmidt and Bjork (1992) for efficient training and transfer, according to which participants should be encouraged to pursue different ways to perform a complex task, Bherer et al. (2005) also assessed the impact of VP versus FP training, as used in Kramer, Larish, et al. (1999). They did not observe superior training and transfer benefits for the VP training over the FP training. The authors argued that the lack of difference between VP and FP training effects might be the result of the considerable amount of task coordination practice that subjects received in both VP and FP conditions. The executive control challenge imposed by their protocol, coupled with the relatively simple nature of the stimuli and responses (two-choice reaction time [RT] tasks with unambiguous stimulus-response mappings), may have been sufficient to engender the training effects that were specific to VP training with more complex tasks. However, it could also be argued that the superiority of VP over FP training would be more likely to emerge if the tasks involved stimuli and output modalities that are more detrimental for older adults, compared to younger adults. Moreover, the skills developed through the VP training protocol might be more likely observable in various transfer conditions. In the present study, we used an analogue of the dual-task training protocol used in Bherer et al. (2005) but with similar input (visual) and output (motor) modalities to compare VP and FP training. Moreover, three combinations of untrained dual-task conditions were used to assess transfer effects of training.

Another interesting aspect of the dual-task training procedure used in Schumacher et al.'s study (see also Bherer et al., 2006) was 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 executed two motor responses to stimuli from two different tasks (dual-task trials). These three different types of trials can provide valuable information to help understand the basic mechanisms involved in dual-task performance. In fact, comparing single-task trials performed in the mixed block to single-task trials performed in the pure block provides a measure of processing requirements to prepare and maintain multiple task sets. Heretofore, we will refer to this performance cost as a task-set cost. The difference in performance between the dual-task trials and single-task trials within the mixed blocks provides a measure of the processing necessary to perceive multiple stimuli and coordinate the execution of two responses. The associated RT cost will be referred to as a dual-task cost. The results of Bherer et al. (2005, 2006) studies showed that both task-set cost and dual-task cost improved through training and that the improvement was substantial and equivalent in both older and younger adults. The improvement in task-set cost can be viewed as an improvement in the ability to prepare and maintain multiple task sets, and suggests that older adults are able to reduce the burden of task requirements through training. This is an important finding if we consider that studies with the task-switching paradigm has shown that older adults have considerable difficulty when they need to be prepared to respond to multiple as compared to a single task (Kray & Lindenberger, 2000), and that this effect is larger with greater response-set overlap between tasks (Mayr, 2001, experiment 2). Moreover, improvement in task coordination strategies, evidenced by decrease in dual-task cost, also seems to contribute to enhanced dual-task performance after training in older and younger adults.

Previous findings thus suggest that dual-task training with adaptive individualized feedback substantially improves dual-task processing in both older and younger adults, even with two manual tasks (similar output), by improving both the ability to maintain multiple task sets and the ability to perform multiple tasks concurrently. However, this has not been shown in dual-task conditions that involve similar input. As mentioned previously, Hein and Schubert (2004) observed an increased susceptibility to *input* interference in dual-tasks in older adults and concluded that parallel processing at the input stage requires cognitive control and should be considered as a source of age-related deficits in dual-task. One goal of the present study was thus to extend our findings to a training condition that involved maximal *input* and *output* interference (two visuomotor tasks). A group of older and younger adults engaged in a dual-task training protocol similar to that used in Bherer et al. (2005), which included task instructions and adaptive feedback conditions. Moreover, using different task-trial conditions allows us to dissociate improvements in task-set and dual-task costs. An original contribution of the present study is to examine these costs, and their modulation through training, when two concurrent tasks are designed to produce large interference effects (similar input and output conditions).

Another goal of the present study was to further document transfer of training effects after dual-task training in older and younger adults. The transfer effects are important to show that dual-task skills improved through training, and that learning entailed more than specific stimulus-response mappings (Batsakes & Fisk, 2000; Ho & Scialfa, 2002). Many previous studies have found either very narrow transfer after cognitive training 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 (Gopher, Weil, & Bareket, 1994; Kramer et al., 1995, 1999). In the present study, we used a variety of transfer tasks, with the same combination of input and output conditions (within-modality transfer task) or a different combination of input conditions (cross-modality transfer condition) in order to investigate the extent to which transfer can be observed with dual-task training. Transfer effects were also measured through improvement in task-set cost and dual-task cost to assess whether dual-task training leads to learning a generalizable set of skills that entail the ability to prepare to perform multiple tasks as well as the ability to execute multiple tasks concurrently.

METHODS

Participants

Forty-four older adults and 44 younger adults participated in the study. The older adult sample was comprised of 24 women and 20 men living in the community, with a mean age of 71 years, and the young group was composed of 26 women and 18 men, with a mean age of 22 years. All participants reported good health (on a 5-point scale mean score was 4.3 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, older participants completed 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 54.3 [*SD* = 2.3] for the training group and 54.8 [*SD* = 1.4] for the control group). Participants were screened for perceptual impairment by completing questionnaires on auditory function and tests for near and far visual acuity. All participants were randomly assigned to either one of the two training protocols or to the control group (VP or FP training or Control). Thirty-two older adults completed the training program (18 in FP and 14 in VP), as did 32 younger adults (16 in FP and 16 in VP). The different training conditions will be further discussed below. However, because of equivalent training effects across the two training conditions, participants from the training groups were pooled and their performance was compared to those of the control groups. Twelve older adults and 12 younger adults composed the control groups.

Table 1 presents demographic and psychometric performance tests for the participants in the study. The psychometric tests were used to characterize our participant populations on different cognitive abilities. The test battery included 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), as well as attention and executive function (Stroop; Trail Making A, B).

Stimuli and Apparatus

The training and transfer tasks were performed on a Macintosh iMac. Participants performed the tasks 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 alternatively appeared in yellow or green. Auditory stimuli were presented via headphones equipped with a volume control so that volume level could be adjusted if needed, although it was set by default to a constant level.

The training tasks included two visual discrimination tasks, performed both separately and concurrently. One visual task was to identify the color of an X appearing on the screen (yellow or green). The second visual task was to identify which of two letters (B or C) was presented on the computer screen. Three different task combinations were used as transfer conditions. In the within-modality transfer task, participants performed two visual identification tasks: pattern discrimination (a solid or a stripped square) and number discrimination (3 and 5). Two cross-modality transfer tasks combinations involving a visual and an auditory task were also used. In the first task combination, participants had to judge whether a tone was low or high in pitch (440 versus 990 Hz, duration = 250 ms). This auditory task was combined with a visual task that required identifying which of two letters (B or C) was presented on the computer screen. The second cross-modality task combination involved an auditory task requiring discriminating between a smooth sound (sine wave 550 Hz) and a rough sound (triangle 550 Hz). This task was performed with a visual identification task that involved numbers (3 and 5). Participants started each trial by depressing the space bar. At this time, a fixation point (*) 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. Participants responded with the index and middle finger of the right or the left hand, one task per hand. Response hand to task mapping was counterbalanced across subjects 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-h neuropsychological testing session (see Table 1), during which they also answered questions on health and demographics. On the second day, participants from the three groups (FP, VP, and control) completed a pretraining (described below) session that lasted about 1 h. The participants in the VP and FP groups next engaged in the training protocol that involved five training sessions (detailed below), each of which took approximately 1 h to complete. An additional session was needed for post-testing for all participants from the three experimental groups (FP, VP, and control). Table 2 shows the task combinations completed by each group of participants. The control subjects did not participate in the training sessions. However, the same amount of time elapsed between pre-and post-training sessions for the control and for the VP and FP groups. Improvement in performance observed after training in the FP and VP groups could thus be compared to test–retest effect observed in the control group. The experiment sessions, which include pre- and post-testing as well as the five training sessions (for the FP and VP but not the control subjects), were completed within a 3-week period.

Pretraining Session—The pretraining session involved four combinations of dual-tasks to establish baseline performance for the training and transfer tasks (within-modality and the two cross-modality transfer conditions). The presentation order of the four task combinations was counterbalanced across subjects, following a Latin Square design, and was kept constant for a given subject over the pre- and post-training 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 only condition one of the two tasks was performed alone. A pure block contained 20 single-task trials. Presentation order of the two pure blocks, one with the color discrimination task only and one with the letter discrimination task only was counterbalanced between sessions but remain fixed within a single session. In the pure block, subjects were asked to respond as quickly and accurately as possible. During the mixed blocks, subjects 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 by presenting 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 mixed-blocks were composed of 40 single-task trials (20 from 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 post-test sessions, no feedback was provided 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, subjects were instructed to complete the two tasks at the same time as fast and accurately as possible, this instruction was constant for both single-mixed and dual-mixed trials.

Training Sessions—In the next five sessions, participants assigned to the VP or FP training groups engaged in the training program with the two visual tasks, color discrimination (yellow or green) and the letter discrimination (B or C) tasks. Control participants only completed pre- and post-test sessions. The training sessions were each composed of pure and mixed blocks of trials presented in an ABA design similar to the pre-training session (pure-mixed-pure). The training sessions differed from the pre- and post-training session in several ways. First, after completing two single-task blocks (20 trials in each block) as in the pretest session, the participants completed a total of eight mixed-blocks of 80 trials, in each of the five training sessions. 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, 1600 single-task trials in the mixed-task blocks, and 1600 dual-task trials in the mixed-blocks.

A second important difference between the training and pre/post-training sessions was that during the training sessions, instructions were provided to induce different prioritization strategies. The training procedure involved two types of between-subject conditions. 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 (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. Three priority instructions were used, each of which were presented two times during an experimental session. The three priority instructions were (1) Respond to the color first; (2) Respond as fast as you can on both tasks; (3) Respond to the letter first. All participants completed eight mixed blocks that included single-mixed and dual-mixed trials. For the VP group, the eight mixed-blocks differed by SOA and task priority. Block presentation was randomized within a training session. It is important to emphasize that whereas priority instructions varied in the first and the last three blocks (6/8 blocks), the two middle blocks always presented the equal priority instructions and always used a fixed 0-ms SOA. In the FP training condition, the participant was asked to equally emphasize both tasks and SOA was 0 ms. That is, in the FP training condition, all mixed-task blocks took the form of the two middle blocks of the VP condition, with a fixed priority instruction and fixed 0-ms SOA. These two middle blocks allowed us to compare the performance of the two groups in an equivalent condition of instruction and SOA over the five training sessions. Analyses of variance (ANOVAs) performed on RT and accuracy data with training groups (VP and FP) as between-subject factor and sessions (five) and trial type (single-pure, single-mixed, and dual-mixed) as within-subject factors indicated that there were no performance or learning differences between subjects in the VP and FP training groups. Consequently, subjects from these two groups are combined into a “training” group in all analyses reported in this paper.

Training sessions also differed from pre/post-training sessions by presenting continuous individualized adaptive feedback. Feedback indicators were presented continuously as 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.

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. The criterion of good performance was continuously updated on an individual basis as the session evolved and the response distribution of the single-task trials changed. Moreover, it 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.

Post-Training—All participants completed a post-training session following the fifth training session. In the post-test session participants completed the four combinations of dual-tasks (i.e., the training tasks, within-modality transfer tasks, as well as the first and the second combinations of cross-modality transfer tasks) following the same order as in the pretraining session.

RESULTS

To characterize our subject groups on their performance on a variety of neuropsychological tests we performed ANOVAs on the neuropsy-chological data presented in Table 1. The ANOVAs involved age (old and young) and training (training versus control) as between-subject factors. Age-related differences in favor of younger adults were observed for box completion, $F(1, 84) = 5.67$, $p < .05$; digit copying, $F(1, 84) = 22.51$, $p < .001$; digit symbol substitution tests, $F(1, 84) = 57.75$, $p < .001$; sequential complexity, $F(1, 84) = 5.84$, $p < .05$; forward digit span, $F(1, 84) = 14.47$, $p < .001$; backward digit span, $F(1, 84) = 16.89$, $p < .001$; computation span, $F(1, 83$[1]$) = 32.84$, $p < .001$; Stroop, $F(1, 84) = 41.98$, $p < .001$; Trail-Making Test A, $F(1, 84) = 16.11$, $p < .001$; and Trail-Making Test B, $F(1, 84) = 26.53$, $p < .001$. Except for box completion in which the training group had lower score, $F(1, 84) = 4.49$, $p < .05$, none of these tests showed a difference between training groups or an interaction between age and training, which suggests that the experimental and the control groups were comparable on cognitive abilities.

The dependent variables of interest in the experimental tasks were RT and accuracy. RT was calculated from stimulus presentation to the subject's response independently for each discrimination task in all single-task trials and dual-task trials. Incorrect responses were not included in the RT analyses, and trials were also rejected if the RT was longer than 3000 ms or shorter than 100 ms. Accuracy was calculated as percentage of correct responses in each condition. Analyses were performed with ANOVAs with two between-subject factors, age group (older versus younger) and training group (training versus control), and three within-subject factors, task (color versus letter), session, and trial type (single-pure, single-mixed, double-mixed). Significant interactions between these factors were decomposed 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), repeated-contrasts were used. Such analyses provide a comparison of RT differences between two consecutive levels of a repeated factor. Statistical analyses of the data were performed with SPSS (SPSS, 1997), which provides adjusted alpha levels (Greenhouse-Geisser) for within-subject factors to correct for violations of homogeneity of variance. An effect is reported significant here according to the adjusted alpha level when required, that is when the Mauchly's test of sphericity was significant (SPSS, 1997). Effect sizes (η^2) are also reported.

The first set of analysis explored participants' performance during the five training sessions, across age and training groups (VP and FP). A second set of analyses was performed to compare performance among groups (training versus control) in all four tasks combinations (Training, within-modality transfer, and cross-modality transfers 1 and 2) completed at pre- and post-test. The same ANOVA model served for the two sets of analyses, with the only difference that the factor session involved two levels in the pre- versus post-test analyses and five levels for training sessions.

Training Sessions

Reaction Time Analyses—Figure 1 shows the mean RT data across the two visual discrimination tasks for the five training sessions. Due to equivalent effects and interaction effects among tasks, results from the two discrimination tasks were pooled together. Two issues were addressed by the analyses reported in this section. The first issue concerned the age-related differences in dual-task performance. The second question was whether age-related differences emerged relative to the effect of training.

Several important results were observed. First, main effects were obtained for age, $F(1, 50) = 52.55$, $p < .001$, $\eta^2 = .51$. Older adults were slower (861 ms) than younger adults (604 ms). Moreover, the main effect of Trial type reached significance, $F(2, 100) = 482.43$, $p < .001$, $\eta^2 = .91$. Repeated-contrasts indicated that RT was longer in single-task trials performed in the mixed blocks (713 ms), interleaved with dual-task trials, compared to those performed in the pure blocks (518 ms), $F(1, 50) = 395.95$, $p < .001$, $\eta^2 = .89$. This indicates significant task-set

[1]Score for computation span is missing for one participant of the group of younger adults.

cost in RT. It was also observed that RT was slower in dual-task trials (967 ms) compared to single-task trials within the mixed blocks (713 ms), $F(1, 50) = 350.93$, $p < .001$, $\eta^2 = .88$. Thus, significant dual-task cost was also observed.

Moreover, task cost differed among age groups, as indicated by a significant Age × Trial Type interaction effect, $F(2, 100) = 26.59$, $p < .001$, $\eta^2 = .35$. Older adults showed both a larger task-set cost (older 224 ms, younger 167 ms), $F(1, 50) = 8.45$, $p < .001$, $\eta^2 = .15$, and a larger dual-task cost (older 329 ms, younger 180 ms), $F(1, 50) = 29.76$, $p < .001$, $\eta^2 = .37$, than younger adults. Note, however, that the Age × Trial Type interaction was no longer significant after controlling for general slowing, $F(2, 98) = 2.28$, n.s., $\eta^2 = .04$.[2]

With regard to the second question of interest, it can be observed that performance improved as a function of training session, but that training effect appears equivalent among age groups. In fact, a main effect of training session was observed, $F(4, 200) = 69.31$, $p < .001$, $\eta^2 = .58$, and repeated-contrasts showed that RTs get faster in each subsequent session (p values < .01). Moreover, a significant Trial Type × Session interaction, $F(8, 400) = 16.24$, $p < .001$, $\eta^2 = .25$, 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, $F(1, 50) = 4.27$, $p < .05$, $\eta^2 = .08$; between sessions 2 and 3, $F(1, 50) = 4.25$, $p < .05$, $\eta^2 = .08$; and between sessions 4 and 5, $F(1, 50) = 7.71$, $p < .01$, $\eta^2 = .13$. Dual-task cost also decreased significantly with training, but only between sessions 4 and 5, $F(1, 50) = 6.21$, $p < .02$, $\eta^2 = .11$. The Age × Session interaction, $F(4, 200) = 3.21$, $p < .01$, $\eta^2 = .06$, was significant. However, this interaction failed to reach significance after controlling for age-related difference in general slowing, $F(4, 196) = 1.23$, n.s. Thus it would appear 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 1*B*. These data were analyzed with the same ANOVA model as used in the RT analyses. Main effects were obtained for age, $F(1, 50) = 8.69$, $p < .01$, $\eta^2 = .15$, older participants (96%) being generally more accurate than younger adults (93%); session, $F(4, 200) = 10.01$, $p < .001$, $\eta^2 = .17$; and trial type, $F(2, 100) = 12.50$, $p < .001$, $\eta^2 = .20$, due to a significant task-set cost, $F(1, 50) = 20.61$, $p < .001$, $\eta^2 = .29$, whereas dual-task cost, $F(1, 50) = 3.43$, n.s., $\eta^2 = .06$, was not significant. A significant interaction between trial type and age, $F(2, 200) = 9.57$, $p < .001$, $\eta^2 = .16$, was also observed. Follow-up analyses showed that the effect of trial type was not significant in older adults, $F(2, 44) < 1$, whereas younger adults showed significant trial type effect, $F(2, 56) = 34.97$, $p < .001$, $\eta^2 = .56$, due to significant task-set cost, $F(1, 28) = 86.57$, $p < .001$, $\eta^2 = .76$, and dual-task cost, $F(1, 28) = 9.01$, $p < .01$, $\eta^2 = .24$.

A significant interaction was also observed between age and session, $F(4, 200) = 10.76$, $p < .001$, $\eta^2 = .18$. Further analyses showed that percentage of accurate responses increased signifcantly with session in older adults, $F(4, 88) = 19.65$, $p < .001$, $\eta^2 = .47$, = .03, especially between the first two sessions, $F(1, 22) = 17.54$, $p < .001$, $\eta^2 = .44$. In younger adults, accuracy did not vary significantly across training sessions.

Pre- Versus Post-Training Analyses

Reaction Time Analysis—In order to quantify the effect of training regimen, improvement observed in the training group was compared to pre- and post-test performance of the control

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[2]Age-related differences in general slowing are well documented in cognitive aging studies (Madden, 2001). In the present study, age-related slowing was controlled for by conducting ANCOVAs with baseline RT in the single pure trials averaged for the two tasks performed alone in the first training session used as covariate. In pre- and post-test analyses, baseline RT was averaged separately for each of the four-task combinations (training, within-modality, and cross-modalities 1 and 2) at pretest. In this study, an interaction involving the age group factor is considered significant only if it was also significant in the ANCOVA.

group that did not engage in dual-task training. We performed four sets of analyses, one for each task combination: training tasks, within-modality transfer tasks, and the first and the second cross-modality transfer tasks. The same ANOVA model used with the training data was used to assess improvement in these tasks, with age group and training (training versus control) as between-subject factors and session and trial type as within-subject factors.

RT data for all four task combinations are shown in Figure 2 and task-set and dual-task cost are depicted in Figure 3. The results were very similar among transfer task combinations, and thus main effects and interactions that are common to all four tasks conditions are summarized in Table 3. With regard to age-related difference in dual-task performance, it can be observed that the age difference was significant among all task conditions. More specifically task-set cost was larger in older compared to younger adults in all conditions. Age-related differences in dual-task cost were also significant in the two task combinations that involved two visual tasks, that is, the training tasks and the within-modality tasks combination. Note also that except for the training tasks, all these effects remained significant after controlling for general slowing.

The second important question was whether training lead to improvements in dual-task performance. The answer appears to be positive as indicated by a significant effect of session in the training tasks. However, the effect of session interacts with trial type and training and the interaction between these three factors, Training Group × Session × Trial Type, was also significant. To understand this interaction, we compared improvement in task-set cost and dual-task costs across experimental groups. Results are shown in Table 3 (see column “Training tasks”). It can be observed that the Training × Session interaction was significant for both task-set cost and dual-task cost. Simple-effects analyses performed separately for the training and the control groups further showed that task-set cost improved to a greater extent in the training group, $F(1, 86) = 165$, $p < .001$, $\eta^2 = .66$, than in the control group, $F(1, 86) = 6.10$, $p < .02$, $\eta^2 = .07$. The training group also showed evidence of improvement in dual-task cost, $F(1, 86) = 119.20$, $p < .001$, $\eta^2 = .58$, which was not observed in the control group, $F(1, 86) = 2.56$, n.s., $\eta^2 = .03$.

The third question of interest is whether a training benefit can be observed in the transfer tasks. These results are also shown in Table 3 (see columns “Within-modality transfer tasks” and “Cross-modality transfer tasks”). The important effect here is the interaction Training × Session × Trial Type, as observed in the training tasks. This interaction was observed in all three transfer tasks. If we look at the within-modality transfer task first, improvement was observed in both task-set and dual-task costs (see Table 3). Simple-effects further indicated that task-set cost improved in the training group, $F(1, 86) = 79.61$, $p < .001$, $\eta^2 = .48$, but not in the control group, $F(1, 86) = 3.01$, n.s., $\eta^2 = .03$. The same results are observed in dual-task cost where the Training × Session interaction is due to significant improvement in the training group, $F(1, 86) = 61.60$, $p < .001$, $\eta^2 = .42$, with no evidence of improvement in the control group, $F(1, 86) = 00$, n.s. The analyses also showed one important result that was specific to the within-modality transfer task (not shown in Table 3). A significant Age × Training × Session interaction, $F(1, 84) = 4.76$, $p < .05$, $\eta^2 = .05$, was observed. This interaction was still significant after controlling for general slowing (with baseline RT at pretest as covariance), which suggests that overall improvement due to training differed among age groups. In fact, simple-effect analyses showed that in the older adults, only the training group, $F(1, 42) = 141.08$, $p < .001$, $\eta^2 = .77$, showed significant improvement from pretest to post-test (control: $F(1, 42) = 1.55$, n.s., $\eta^2 = .04$). But in younger adults, despite larger improvement in the training group, $F(1, 42) = 206.15$, $p < .001$, $\eta^2 = .83$, the control group, $F(1, 42) = 12.48$, $p < .001$, $\eta^2 = .23$, also showed improvement in RT.

With regard to cross-modality transfer, a very consistent pattern was observed in the two transfer tasks. In fact, the three-way Training × Session × Trial Type interaction was significant in the cross-modality transfer tasks 1 and 2. In both cases, a significant effect of training, as shown by the Training × Session interaction was observed in task-set cost only, with virtually no improvement in dual-task cost. In both cross-modality transfer tasks, simple-effects showed large and significant improvement in task-set cost for the training group (Task 1, $F(1, 86) = 101.86$, $p < .001$, $\eta^2 = .54$; Task 2, $F(1, 86) = 61.17$, $p < .001$, $\eta^2 = .42$), whereas the control group show a slight improvement in the second cross-modality transfer task, $F(1, 86) = 4.65$, $p < .05$, $\eta^2 = .05$, with no improvement in the first cross-modality transfer task, $F(1, 86) < .01$, n.s.

Accuracy Analysis—Mean percentage of correct responses obtained in pretraining and post-training sessions are shown in Figure 4. As observed in RT, results are relatively consistent in the four task combinations. It can be observed that percentage of correct answers increased with training. Moreover, the improvement appears larger in older compare to younger adults. These observations were confirmed by the results of ANOVAs using the same model as used for RT data with age and training as between-subject factors and session and trial type as within-subject factors. Results of the ANOVAs are presented in Table 3. A common finding for the training task as well as the three transfer tasks is that accuracy improvement was larger in older adults than younger adults, as indicated by a significant Age × Session interaction (Table 3). Simple-effects analyses further confirmed that improvement in accuracy was significant and substantial in older adult in the training task, $F(1, 86) = 15.58$, $p < .001$, $\eta^2 = .15$; the within-modality transfer task, $F(1, 86) = 20.14$, $p < .001$, $\eta^2 = .19$; the first cross-modality task, $F(1, 86) = 43.59$, $p < .001$, $\eta^2 = .34$; and the second cross-modality transfer task, $F(1, 86) = 19.64$, $p < .001$, $\eta^2 = .19$. No significant improvement was observed in younger adults in the four task combinations, with $F(1, 86) \leq 3.2$, n.s. and $\eta^2 = .00$–$.04$ in all four conditions.

Apart from the results reported in Table 3, we observed a Training × Session × Trial Type, $F(2, 168) = 3.48$, $p < .05$, $\eta^2 = .04$, in the within-modality transfer task. This interaction was due to a significant Session × Trial type interaction, $F(2, 126) = 10.05$, $p < .001$, $\eta^2 = .14$, in participants of the training group, due to larger improvement from pre-test to post-test in dual-mixed trials (92 to 95) compared to single-mixed trials, (95 to 95), leading to a reduction in dual-task cost. Note that this effect was equivalent among older and younger adults. Moreover, no effect of session or interaction effect with session was found in the control group.

One important finding in the accuracy data that involved age-related differences in transfer effects was a significant four-way interaction, Age × Training × Session × Trial Type, which was observed in both the first cross-modality transfer tasks, $F(2, 168) = 3.10$, $p < .05$, $\eta^2 = .04$, and the second cross-modality transfer task, $F(2, 168) = 3.34$, $p < .05$, $\eta^2 = .04$. Follow-up analyses of the four-way interactions were performed by comparing age group in the training and the control conditions separately in order to see whether the differential effect of session on trial type was specific to the training group as was previously observed in the within-modality transfer task. The results showed a significant Age × Session × Trial Type in the training group (first cross-modality transfer tasks, $F(2, 124) = 5.74$, $p < .01$, $\eta^2 = .09$; second cross-modality transfer task, $F(2, 124) = 7.23$, $p < .001$, $\eta^2 = .10$). This interaction effect was not observed when the control groups were compared (first cross-modality transfer tasks, $F(2, 44) < 1$, n.s; second cross-modality transfer task; $F(2, 44) = 1.02$, n.s.). Follow-up analyses to the Age × Session × Trial Type interaction in the training groups showed differential improvement as a function of trial type in older adults, but not younger adults, as indicated by a Session × Trial Type interaction only in older adults (first cross-modality transfer tasks; $F(2, 62) = 9.65$, $p < .001$, $\eta^2 = .24$; second cross-modality transfer task, $F(2, 62) = 10.10$, $p < .001$, $\eta^2 = .25$). In both transfer tasks, the Session × Trial Type interaction was due to larger improvement in single-mixed trials compared to single-pure trials (first cross-modality transfer tasks, $F(1, 31) = 6.97$, $p < .01$, $\eta^2 = .18$; second cross-modality transfer task, $F(1, 31) = 13.77$, $p < .001$, $\eta^2 = .31$), indicating a reduced task-set cost after training. Improvement in percentage of correct responses in the single-mixed trials was respectively 88 to 95 and 88 to 93, for the first and the second cross-modality transfer tasks. In pure single-tasks trials, respective changes from pretest to post-test were 93 to 95 and 93 to 92. A significant effect was also found, $F(1, 31) = 4.96$, $p < .05$, $\eta^2 = .14$, when improvement in dual-mixed (82 to 93) trials was compared to improvement in single-mixed trials (88 to 95), suggesting significant decrease in dual-task cost, but this effect was only observed in the first cross-modality transfer task and to a lesser degree than improvement in task-set cost. In the second cross-modality transfer task, accuracy improvement was comparable in dual-mixed trials (85 to 91) and in single-mixed trials (88 to 93). All together, accuracy data in the cross-modality transfer tasks are quite consistent in showing larger improvement after training in task-set cost in older adults compared to younger adults.

DISCUSSION

The present study assessed the extent to which dual-task performance can be improved through training in older and younger adults, when two concurrent tasks involve similar input (visual) and output modes (manual responses). Continuous, individualized adaptive feedback and instructions were provided to the participants during training. To assess whether acquired task coordination skills generalize to untrained stimuli, within and between modalities, performance improvement was assessed at pretraining and post-training sessions in the training tasks (in which feedback was not presented) as well as in three transfer tasks, a within-modality transfer task, and two cross-modality transfer tasks. Moreover, we explored whether training leads 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. Comparison of 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 mixed dual-task trials - RT in mixed single-task trials).

The results reported here provide important insights into age-related differences in dual-task performance and the benefit of training to enhance dual-task skills in older adults. First, we observed age-related differences in dual-task performance in all task combination. The age-related difference was due to both larger task-set cost and dual-task cost in older adults compared to younger adults. However, after controlling for general slowing, by using single-task pure trials in each task as a baseline speed level, we observed that the age-related differences in dual-task cost remained significant when the two concurrent tasks tap the same input and output modalities (two visuomotor tasks of the within-modality transfer condition; see Table 3), but only task-set cost remained sensitive to age-related differences when a visual task was combined with an auditory task (observed in both cross-modality transfer conditions). These results are consistent with previous studies with older adults (Hartley, 2001;Hein & Schubert, 2004). In fact, they suggest that when two tasks produce maximal input and output interference, older adults are more disadvantaged than younger adults. Thus older adults' deficit in this condition is likely due to difficulty in coordination and execution of the two tasks at the same time. However, when only the output modality is similar, and input differed (visual combined with auditory discrimination), the larger age-related difference is mostly due to larger task-set cost in older adults, which suggest greater difficulty in the capacity to hold multiple stimuli and responses in memory.

With regard to the benefit of dual-task training, our results suggest that both older and younger adults benefited from dual-task training as observed in the training task as well as in the three transfer conditions. During training sessions, task-set cost starts to decrease as early as the first two sessions, whereas dual-task-costs decrease only from sessions 4 to 5. In general, older and younger adults show equivalent improvement in RT, with older adults showing larger improvement in accuracy. Improvement in dual-task performance in the three transfer tasks suggests that training leads to the development of somewhat general task coordination strategies. In fact, substantial improvement was observed in RT between pre- and post-test sessions in all four task combinations (see Table 3). We observed significant improvement in both task-set cost and dual-task cost in the training tasks and the within-modality transfer task. Interestingly, only task-set cost improved in the two cross-modality transfer tasks. This is an important finding that can set limits on the nature of transfer of training with dual-tasks. Note also the absence of an interaction with age, suggesting that transfer effects are equivalent in both older and younger adults.

A difference that emerged between older and younger adults in RT data is that only the training group of older adults showed improvement in RT in the within-modality transfer task. In younger adults, however, control participants also showed significant improvement as a result of retesting. We also observed similar effects in a previous study (Bherer et al., 2005). It thus appears that the training effect, as measured as differential improvement between training and control condition, can sometimes be more beneficial for older than younger adults.

Whereas training effects measured in RT data are similar for older and younger adults, accuracy data showed a somewhat different picture. In fact, with regard to the percentage of correct responses, older adults showed much larger improvement than younger adults in the training tasks as well as in the transfer tasks. In terms of age-related differences in dual-task training, another important finding in accuracy data was that in the two cross-modality transfer tasks, older adults showed a larger decrease in task-set cost compared to younger adults. It thus seems that whereas older adults achieved the same level of improvement as younger adults in task-set cost expressed in RT in the two cross-modality transfer tasks, they showed larger improvement than younger adults in accuracy. Overall, dual-task training appears to have lead to more substential improvement of performance in older compared to younger adults.

Several studies have reported age-related deficits in divided attention (McDowd & Shaw, 2000; Hartley, 1992; see Verhaeghen et al., 2003, for a meta-analysis). A contribution of the present study is the dissociation between task-set and dual-task costs attributable to the coordination of multiple tasks. The data obtained in the present study suggest that task-set cost is a major source of problems for older adults, but dual-task costs should also be considered as a potential source of difficulty for older adults, especially when two tasks share input and output modalities. Age-related differences in task-set cost are consistent with results frequently observed in task-switching studies. 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 numbers of trials in one task, they must rapidly switch to the other task. Age-related RT differences have been repeatedly observed when performance is compared between switch blocks and pure-task trial blocks (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000). Thus, in both dual-task and task-switching paradigms, older adults have more difficulty preparing for multiple tasks than they do either switching between two tasks or performing multiple tasks concurrently. This could partly explain age-related deficit observed in dual-tasks.

An important issue in cognitive training is whether the benefit of training generalizes to different stimuli and tasks (Kramer & Willis, 2003; Schmidt & Bjork, 1992). Another contribution of the present study was to assess transfer of task coordination skills in three conditions; within-modality and two combinations of cross-modality transfer tasks. A new stimulus set was introduced for both visual tasks in the within-modality transfer condition. Performance improvements for the within-modality transfer task, when the control group was compared to the training group, were quite similar to that observed for the trained stimuli. Both task-set and dual-task performance costs were substantially reduced for both the younger and the older training subjects, but not for the control group. Furthermore, transfer benefits were similar for the two age groups in RT. However, improvement in accuracy was larger in older than younger adults.

In the cross-modality transfer condition, subjects concurrently performed an auditory discrimination task and a visual discrimination task. In this condition, both young and older adults in the training groups showed significant reductions in task-set cost, which was not observed for the control subjects. This is an important finding and suggests that dual-task skills were improved through training, and that learning entailed more than specific stimulus-response mappings (Batsakes & Fisk, 2000; Ho & Scialfa, 2002). However, it is also important to emphasize that dual-task costs did not show the same improvement in these cross-modality transfer conditions. Consistent with the view that task-set cost better reflects the ability to prepare for and manage multiple task-set in memory, and that dual-task cost rather reflects the ability to coordinate the execution of two concurrent tasks, it seems that cross-modality transfer effect in the dual-task training paradigm used in this study is mainly supported by enhanced ability to prepare and maintain multiple-task sets. Be that as it may, overall, the transfer data suggest that subjects learned a somewhat generalizable set of skills that entail the ability to manage multiple tasks. Whether such skills will generalize beyond two-choice discrimination tasks is an important question for future research.

It is interesting to note that whereas training and transfer effects reported in this study were equivalent among older and younger adults in RT data, improvement in accuracy was larger in older adults in all conditions. It thus seems that training benefits in the domain of attentional control, as in dual-task training, are equivalent in older and younger adults. Previous studies have shown reduced training effects when older adults are compared to younger adults in memory training, which suggests that at least in the memory domain, cognitive plasticity is decreased in older adults (Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995). Our results suggest that in the domain of attentional control, cognitive plasticity is still possible in old age. However, it is important to note that in most previous studies of age-related differences in learning, subjects have been asked to practise tasks without the benefit of individualized adaptive feedback that was available for the training subjects 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.

Finally, it is interesting to note that in the present study, similar training effects were observed for FP and VP training protocols. As discussed in the introductory section, 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, 1999), which was attributed 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). The absence of VP superiority effect in the present study is consistent with previous results with a similar training paradigm (Bherer et al., 2005) and can be related to the nature of the tasks employed. Participants performed two-choice discrimination tasks in which stimuli were presented discretely and at fixed temporal intervals as opposed to Kramer et al.'s (1999, 1995) study that used 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). Clearly, the coordinative possibilities are less 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 both VP and FP training conditions in the present study involved a considerable amount of task coordination practice in challenging feedback conditions, which, combined with the simplicity of the tasks, may have been sufficient to engender the training effects that were specific to VP training with more complex tasks. Future studies will be necessary to further examine the relationship between training flexible prioritization of tasks and task characteristics.

In summary, the results reported here indicate that, even with similar motor responses and two visual stimuli (maximal *input* and *output* interference), older and younger adults showed substantial gains in dual-task performance after training, which generalized to new task combinations involving new stimuli. Training has substantial and age-equivalent benefits for both the ability to maintain multiple task sets (task-set cost) and the ability to perform multiple tasks concurrently (dual-task cost).

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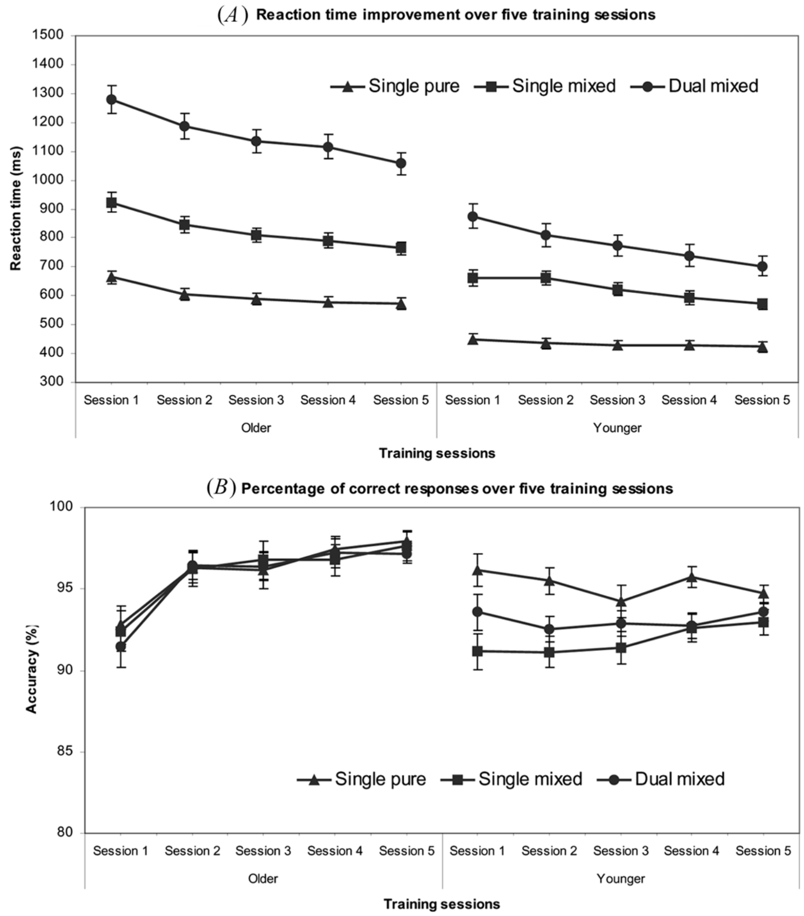

Figure 1.
(*A*) Mean reaction time (ms) and (*B*) percentage of correct responses for older and younger adults in the three trial types (single-pure, single-mixed, and dual-mixed) as a function of the five training sessions.

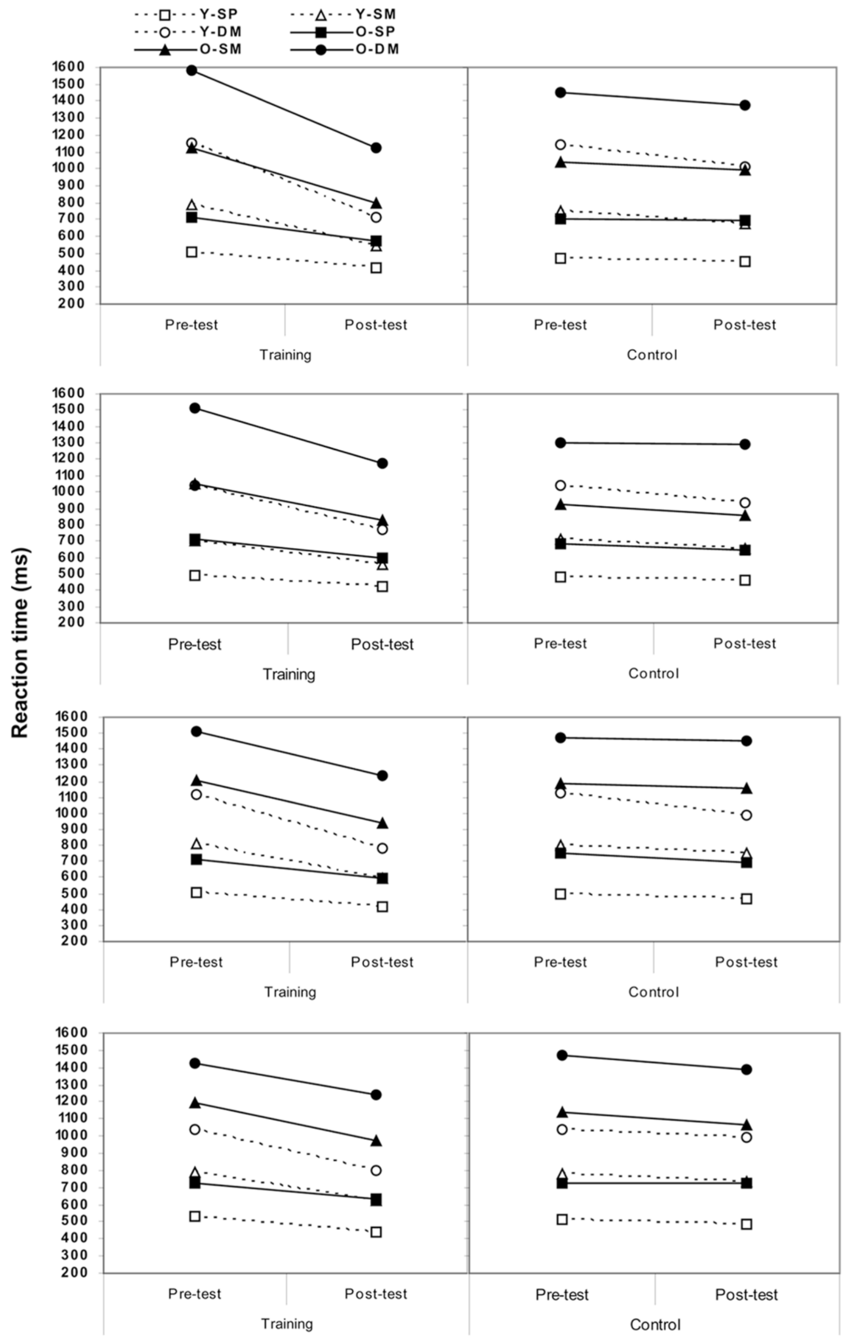

Figure 2.

Mean reaction time (ms) for older and younger adults in the three trial types (single-pure, single-mixed, and dual-mixed) as a function of pre-training and post-training session, for the training tasks (*upper panel*), the within-modality transfer tasks (*upper middle panel*), the cross-modality transfer tasks (*lower middle panel*), and the second cross-modality transfer tasks (*bottom panel*).

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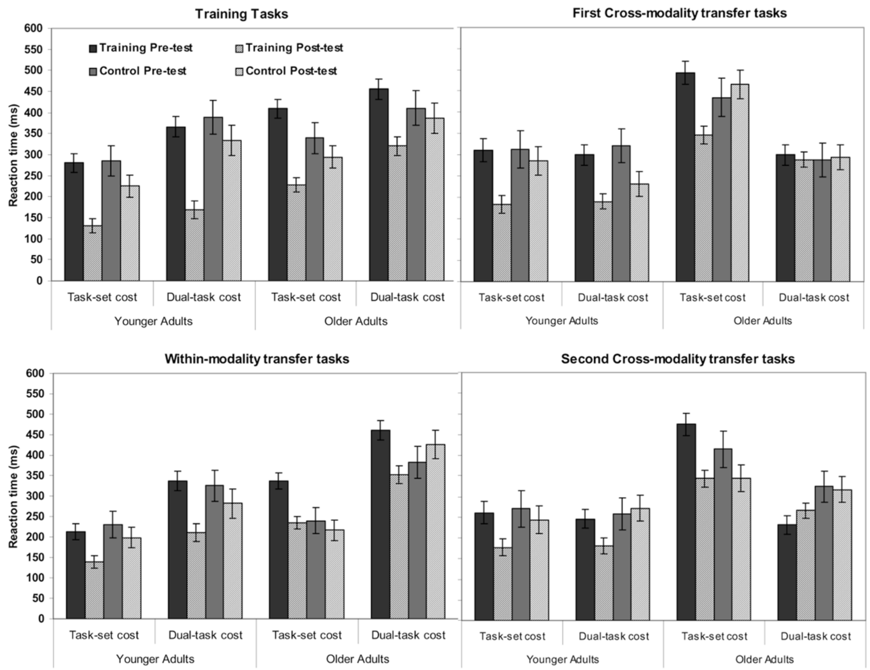

Figure 3.

Mean task-set cost and dual-task cost in the training and control groups of older and younger adults, at pretraining and post-training session for the training tasks and the transfer tasks.

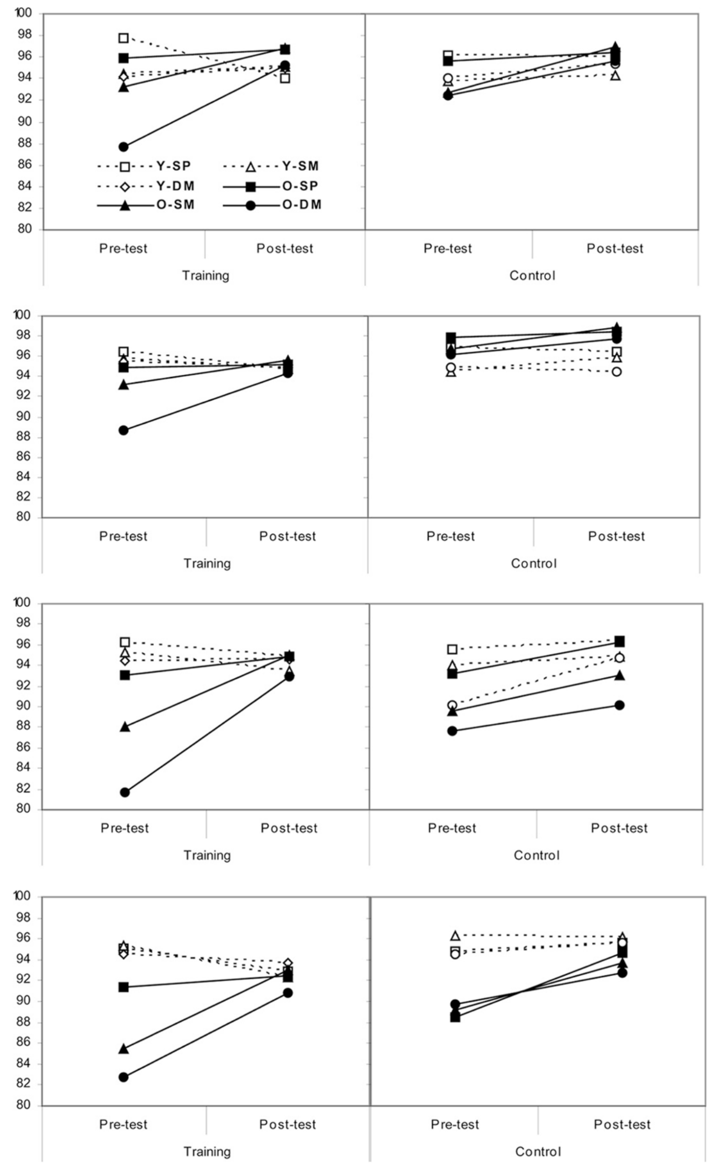

Figure 4.

Percentage of correct responses produced by older and younger adults in the three trial types (single-pure, single-mixed, and dual-mixed) as a function of pretraining and post-training session, for the training tasks (*upper panel*), the within-modality transfer tasks (*upper middle panel*), the cross-modality transfer tasks (*lower middle panel*), and the second cross-modality transfer tasks (*bottom panel*).

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Table 1

Demographic and psychometric performance (mean and standard deviations) for the four groups of subjects

	Older		Younger	
Groups	**Training**	**Control**	**Training**	**Control**
Age	70.38 (5.9)	71.67 (7.0)	22.06 (3.5)	20.75 (1.5)
Health	4.31 (.6)	4.33 (.7)	4.58 (.64)	4.50 (.67)
School	15.70 (3.2)	14.17 (2.1)	16.13 (3.0)	14.45 (1.5)
Near visual acuity	20/25	20/22	20/21	20/20
Far visual acuity	20/25	20/21	20/21	20/20
Kaufman brief intelligence test	116.34 (9.8)	112.25 (8.9)	110.44 (7.5)	113.83 (11.6)
Box completion (correct answers)	36.94 (11.3)	43.5 (14.22)	44.25 (12.1)	49.8 (10.3)
Digit copying (correct answers)	59.69 (11.6)	62.17 (13.9)	72.69 (11.3)	75.33 (8.9)
Digit symbol (correct answers)	34.56 (6.8)	33.17 (7.3)	47.34 (7.7)	46.92 (7.5)
Sequential complexity (correct answers)	35.69 (12.6)	37.67 (11.1)	46.31 (11.5)	40.67 (10.9)
Forward digit span	8.06 (2.2)	8.25 (1.9)	9.75 (1.8)	10.25 (2.1)
Backward digit span	7.06 (2.1)	5.92 (2.0)	8.88 (2.2)	8.50 (2.8)
Computation span	3.03 (1.2)	2.83 (1.0)	5.03 (1.6)	4.58 (1.6)
Stroop test (correct answers)	35.84 (8.8)	34.92 (8.9)	50.97 (10.1)	49.25 (10.1)
Trail-Making Test A (time in s)	38.16 (17.1)	32.92 (9.56)	24.38 (8.5)	22.92 (7.4)
Trail-Making Test B (time in s)	83.06 (34.8)	76.58 (17.1)	48.06 (12.1)	49.92 (25.5)

Note. Scores represent number of correct answers, number of correct sequence (span tests), and time to complete the tasks (in seconds).

Table 2

Dual-task combinations completed by the three groups (VP, FP, control) of participants during the experimental sessions

Task, combination	Pre-test	Training sessions	Post-test
Training tasks	VP, FP, control	VP, FP	VP, FP, control
Letter + color discrimination			
Within-modality transfer tasks	VP, FP, control		VP, FP, control
Number + pattern discrimination			
Cross-modality transfer tasks 1	VP, FP, control		VP, FP, control
Tone + letter discrimination			
Cross-modality transfer tasks 2	VP, FP, control		VP, FP, control
Tone + number discrimination			

Note. Experimental sections include pre-test, post-test, and five training sessions.

Table 3

Results of the ANOVAs performed on RT and Accuracy for the four task combinations used in the pretraining and post-training sessions

	Task combination											
	Training tasks			Within-modality transfer tasks			Cross-modality transfer tasks 1			Cross-modality transfer tasks 2		
	df	*F*	*p*<	*df*	*F*	*p*<	*df*	*F*	*p*<	*df*	*F*	*p*<
Reaction time(ms)												
Age group	1, 84	74.45	.001	1, 84	63.04	.001	1, 84	78.15	.001	1, 84	79.87	.001
Session	1, 84	220.58	.001	1, 84	133.88	.001	1, 84	116.06	.001	1, 84	86.58	.001
Trial type	2, 168	751.30	.001	2, 168	692.61	.001	2, 168	706.24	.001	2, 168	724.15	.001
Age × Trial Type#	2, 168	13.04	.001	2, 168	17.09	.001*	2, 168	19.28	.001*	2, 168	24.93	.001**
Age difference on task-set cost	1, 84	14.11	.001	1, 84	7.86	.01	1, 84	29.31	.001*	1, 84	28.30	.001**
Age difference on dual-task cost	1, 84	7.81	.01	1, 84	18.44	.001*	1, 84	1.81	n.s.	1, 84	4.45	.05
Training × Session	1, 84	92.36	.001**	1, 84	44.90	.001**	1, 84	40.46	.001**	1, 84	26.40	.001**
Session × Trial type	2, 168	91.64	.001	2, 168	39.02	.001	2, 168	24.19	.001*	2, 168	18.74	.001**
Training × Session × Trial type	2, 168	29.45	.001**	2, 168	23.42	.001**	2, 168	12.91	.001**	2, 168	3.33	.05*
Training × Session in task-set cost	1, 84	21.09	.001**	1, 84	10.15	.01*	1, 84	28.79	.001**	1, 84	5.16	.05*
Training × Session in dual-task cost	1, 84	19.37	.001**	1, 84	17.12	.001**	1, 84	.34	n.s.	1, 84	.45	n.s.
Accuracy (%)												
Age group	1, 84	.15	n.s.	1, 84	.03	n.s.	1, 84	7.91	.01	1, 84	5.92	.01
Session	1, 84	4.94	.03	1, 84	3.72	n.s.	1, 84	16.55	.001	1, 84	4.26	.01
Age × Session	1, 84	5.52	.02	1, 84	8.95	.01	1, 84	10.41	.01	1, 84	14.57	.001
Trial type	2, 168	8.53	.001	2, 168	8.83	.001	2, 168	22.70	.001	2, 168	2.50	n.s.
Trial Type × Session	2, 168	8.95	.001	2, 168	4.98	.01	2, 168	4.33	.02	2, 168	1.09	n.s.

#To control for general slowing, ANCOVAs were performed using mean RT in single-pure trials at pretest in each of the task combinations as covariate. For each interaction involving the Age group factor.

*Indicates that the interaction remained significant at .05 level after adjustment for general slowing.

**The effect remained significant at .01 level after adjustment for general slowing.