Journal of Experimental Psychology: Applied
1995, Vol. 1, No. 1, 50–76

Training for Attentional Control in Dual Task Settings: A Comparison of Young and Old Adults

Arthur F. Kramer and John F. Larish
Beckman Institute, University of Illinois at Urbana–Champaign

David L. Strayer
University of Utah

The authors examined whether the learning and performance of dual tasks by young and old adults could be enhanced through training. Adults were trained with either a fixed-priority or variable-priority training strategy on a monitoring task and an alphabet–arithmetic task and then transferred to a scheduling and a paired-associates running memory task. Participants in the variable-priority condition learned the monitoring and alphabet–arithmetic tasks more quickly and achieved a higher level of mastery on these tasks than did those in the fixed-priority condition. Moreover, participants trained with the variable-priority technique showed evidence of the development of automatic processing and a more rapid rate of learning and higher level of mastery of the transfer tasks than did the fixed-priority participants. These results are discussed in terms of the mechanisms that underlie learning and performance of dual tasks and with respect to potential applications.

Robust age-related decrements in dual task performance have been reported by numerous investigators over the past 25 years. Unfortunately, however, there has been a conspicuous absence of research directed to the question of whether older adults have the capability to improve their dual task performance through practice and training and whether such improvements might parallel those exhibited by younger adults or instead narrow or eliminate the age-related gap in dual task performance. It is this question that forms the basis of our research program on the influence of training strategies on the learning, performance, and transfer of dual task–processing skills for younger and older adults.

The study of age differences in dual task performance and their possible modulation through training has important theoretical and practical implications. For example, a number of theories of aging (Birren, 1965, 1974; Cerella, 1985; McDowd & Craik, 1988; Salthouse, 1985) suggested that older adults' response times are a linear function of younger adults' response times. Within such a theoretical framework, all tasks, whether single or dual, are treated equivalently. A finding of dual task specific training and transfer benefits would suggest that dual tasks are not simply complex single tasks, as asserted by general slowing and complexity models, but that instead the performance of dual tasks involves additional processing operations, such as task coordination and integration. Of course, an important question is whether age-related differences in the efficacy of these processes can be mediated by training.

On the practical side, most leisure and work-

Arthur F. Kramer and John F. Larish, Department of Psychology and Beckman Institute, University of Illinois at Urbana–Champaign; David L. Strayer, Department of Psychology, University of Utah.

This research was supported by National Institute on Aging Grant AG12203. We thank David Burns, Joseph DeAntonna, Heather Pringle, and Ron Wolfman for their assistance in collecting the data and Dan Fisk and Joan McDowd for their helpful comments on the manuscript of this article.

Correspondence concerning this article should be addressed to Arthur F. Kramer, Beckman Institute, University of Illinois, 405 North Mathews Avenue, Urbana, Illinois 61801. Electronic mail may be sent via Internet to akramer@s.psych.uiuc.edu.

place activities involve the learning and performance of multitask skills. For instance, driving involves continuous manual control, scanning for pedestrians and other vehicles, and navigational planning. Ball, Owsley, and colleagues (Ball & Owsley, 1991; Owsley, Ball, Sloane, Roenker, & Bruni, 1991) suggested that automobile accident rates among elderly adults can be predicted, in part, by performance scores on laboratory-based dual tasks. Therefore, it is reasonable to suppose that training strategies that support efficient dual task learning and performance might have some utility for driving and a variety of other real world tasks.

Aging and Dual Task Processing

Craik (1977, p. 391), in his summary of the dual task and aging literature, suggested, "One of the clearest results in the experimental psychology of aging is the finding that older subjects are more penalized when they must divide their attention." Recent examinations of the relation between aging and dual task decrements have with few exceptions obtained results that confirm the earlier findings (Crossley & Hiscock, 1992; Korteling, 1991, 1993; Lorsbach & Simpson, 1988; McDowd, 1986; McDowd & Craik, 1988; Nestor, Parasuraman, & Haxby, 1989; Park, Smith, Dudley, & Lafronza, 1989; Ponds, Brouwer, & van Wolffelaar, 1988; Salthouse, Rogan, & Prill, 1984; but see Somberg & Salthouse, 1982; Wickens, Braune, & Stokes, 1987).

It is important to mention, however, that, although there is a general consensus about the robustness of the dual task or divided-attention effects, there is some disagreement as to the theoretical mechanisms that underlie these age-related differences in performance. One proposal concerns the relative *complexity* of single and dual tasks (McDowd, 1986; Salthouse, 1982). McDowd and Craik (1988, p. 267) stated, "It does not seem that the division of attention presents some especial difficulty to older people. Rather, division of attention is one of several equivalent ways to increase overall task complexity. In turn, age differences are exaggerated as tasks are made more complex." McDowd and Craik (1988) examined the complexity hypothesis by manipulating the difficulty (e.g., through manipulations that would presumably influence depth of processing) and complexity (e.g., number of choices) of a variety of single and dual task combinations. According to the complexity hypothesis, older adults should be proportionally slower than younger subjects as the complexity of the tasks being performed increases, regardless of whether the tasks are performed in a single or dual task paradigm. McDowd and Craik's findings provided partial support for their hypothesis because, for most of their tasks, increases in complexity or difficulty served to increase age-related differences in performance.

The complexity hypothesis, as applied to single and dual task aging differences, shares much in common with an earlier argument that age-related differences in processing speed can be accounted for by a general slowing factor (Birren, 1974; Birren, Woods, & Williams, 1980; Cerella, 1985; Salthouse, 1985). The general slowing proposal, like that of the complexity hypothesis, suggests that older adults' response speed can be well predicted by a linear function of the form, $\text{Old} = s * \text{young} + i$, with s (slope) approximately equal to 1.5 and i (intercept) equal to 0. More recently, nonlinear functions have been found to provide a slightly better account of the relation between the processing speed of young and old adults (Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990).

Although the complexity hypothesis and its general slowing parent provide a relatively good account of the single and dual task data, several pieces of evidence suggest that age-related differences in dual task processing may involve more than a generalized complexity effect. First, although the complexity hypothesis predicts that older adults' responses will be proportionally slower than younger subjects' responses, a number of dual task studies have found disproportionate age-related dual task costs (Crossley & Hiscock, 1992; Madden, 1986, 1987; Park et al., 1989; Ponds et al., 1988; Salthouse et al., 1984). Second, some studies have found larger age-related differences in performance in less rather than more complex tasks (Crossley & Hiscock, 1992; Korteling, 1991; McDowd & Craik, 1988). Third, a number of studies have found selective rather than general age-related differences in dual task performance (Jennings, Brock, & Nebes, 1990; Salthouse et al., 1984; Wickens et al., 1987). For example, Park and colleagues (1989) found age-related differences in encoding but not in retrieval when a categorization and a number-monitoring task were concurrently performed.

In addition to the exceptions to the complexity hypothesis just described, it is important to note that this hypothesis is descriptive rather than explanatory. Thus, an important question is why older adults are at a disadvantage with increasing single or dual task complexity. One proposal is that there is a decrease in capacity or resources during aging, and, therefore, more difficult single and dual tasks will show proportionally larger age-related decrements because they require more resources than easier tasks. Resources have been conceptualized in terms of working memory capacity (Baddeley & Hitch, 1974; Craik, 1977; Welford, 1977), attentional or mental energy (Freidman & Polson, 1981; Kahneman, 1973; Wickens, 1980), and the rate of performing different mental operations (Cerella, 1985; Salthouse et al., 1984). At present, there seems to be reasonable evidence that each of these mechanisms may be responsible, in part, for age-related differences in dual task processing. However, none of these mechanisms in and of themselves appears sufficient to account for all of the instances of age-related dual task–processing decrements. For example, although older study participants show larger dual task processing decrements than younger participants in tasks that rely heavily on working memory (Park et al., 1989; Parkinson, Lindholm, & Urell, 1980; Salthouse et al., 1984), age-related decrements have also been reported in perceptual and motor tasks (Hawkins, Kramer, & Capaldi, 1992; Korteling, 1991; Ponds et al., 1988).

Another proposal offered to account for age-related differences in dual task processing is that older participants have more difficulty managing or coordinating multiple tasks (Korteling, 1991; Salthouse et al., 1984). Several pieces of evidence support this hypothesis. One important finding is that older adults are less proficient than younger adults in the rapid and strategic redeployment of attention among two or more tasks or processes (Korteling, 1991; McDowd, Vercruyssen, & Birren, 1991). One example of this lack of control or attentional flexibility was illustrated in a study by Hawkins and colleagues (1992) in which older adults experienced more difficulty than younger adults when required to switch rapidly between an auditory task and a visual task. Another example is provided by Jennings and co-workers (1990), who found that older study participants were less well prepared for rapidly presented stimuli when required to perform an arithmetic task concurrently with a monitoring task. The proposal of age-related differences in task coordination or attentional flexibility is also consistent with findings that older adults exhibit less flexibility than young adults in varying their speed–accuracy criteria (Hertzog & Vernon, 1993; Sharps & Gollin, 1987; Strayer, Wickens, & Braune, 1987; Welford, 1958), adjusting response speed after errors (Rabbitt, 1979), selecting between different mnemonic strategies (Brigham & Pressley, 1988), and coordinating patterns of movements between their hands (Stelmach, Amrheim, & Goggin, 1988).

In summary, it is clear that large and robust age-related differences in dual task performance are obtained in many situations. It also seems prudent to assume at present that these differences may be the result of changes in several underlying mechanisms. In the subsequent section, we examine the influence of practice and training on dual task performance in an effort to understand further the mechanisms that support dual task performance.

Aging and the Influence of Training and Practice on Dual Task Processing

The major focus of our research is the examination of the influence of training on the dual task performance of young and elderly adults. More specifically, we are interested in how processing changes with training and whether these changes differ over the adult years. Furthermore, we are interested in the relative efficacy of different training strategies in terms of acquisition, mastery, and transfer of dual task skills for both younger and older adults.

Unfortunately, there is a dearth of studies in the literature that examine training and practice effects on the dual task processing of younger and older adults. McDowd (1986) examined the hypothesis that age-related differences in dual task processing could be reduced with practice. Her hypothesis was based on previous reports of such effects with single tasks (e.g., Mowbray & Rhoades, 1959; Murrell, 1970; Nebes, 1978; but see Salthouse, 1990, for a different conclusion). Six young and 6 old adults performed a visual-tracking and auditory choice reaction time (RT) task for 6 hr. Although both old and young adults showed improvements in dual task performance with practice, the age-related difference remained constant.

In a more recent study (Baron & Mattila, 1989), 12 younger and 12 older adult men practiced for 44 hr on a memory scanning procedure in which lists of visual and auditory stimuli were presented both separately and together. Participants made one response on a probe trial if a target was present and another response if a target was not present. In general, the older participants performed the task more slowly than the younger participants in both the single- and dual list conditions. Practice on the task produced only small improvements in performance for both young and older participants. The small practice effects are not particularly surprising because the mapping between stimuli and responses was varied over trials (Fisk & Rogers, 1991a; Schneider & Shiffrin, 1977). However, when a time limit on responding was imposed such that participants were rewarded if they responded faster than the 75th percentile of their previous block of trials, the age-related difference in single- versus dual list conditions was reduced. Furthermore, this reduced age-related decrement remained even when the time contingency was removed.

These results suggest that it may be possible with particular training strategies to reduce the age-related decrements in dual task processing. However, although this study provides some intriguing data, there are a number of unanswered questions. First, it is unclear whether this procedure constitutes a dual task given the simultaneous presentation of two different lists of items that required only a single response. In fact, Logan and Stadler (1991) demonstrated that study participants will often use a *superspan* strategy in which they combine two lists of items into a single list and perform single search through the items of this combined list. Second, given the varied mapping of stimuli to responses in this paradigm, it was impossible to assess whether training would lead to automatized processing for either the old or young participants. Fisk and Rogers (1991b) reported that, with consistent mapping of stimuli to responses, both old and young subjects develop automatic processing in memory but not in visual search tasks. Finally, the lack of a separate set of transfer tasks makes it impossible to determine whether training led to a generalizable information-processing skill. That is, would the old and young adults be capable of using the time limit strategy in the learning of new tasks and skills?

In summary, the literature on dual task practice and training effects for older adults is quite limited despite the theoretical and practical importance of this issue. However, the common finding is that older adults are capable of improving their performance in dual task situations. At present, it is uncertain whether age-related decrements in dual task processing can be reduced or eliminated through practice or the application of specific training strategies. The influence of practice and training on the nature of dual task processing is also unclear. That is, is the dual task improvement that accompanies training a result of the learning or automatization of the single tasks, or is the improvement in performance the result of the development of a dual task processing or task coordination strategy? Before describing our study, we briefly examine the general training literature in an effort to uncover the types of training strategies that might prove useful in improving the dual task processing performance of younger and older adults.

Dual Task Training: General Literature

Two general classes of training strategies have been used in dual task settings: part-task and whole-task training techniques (Damos, 1991; Lintern & Wickens, 1991). *Part-task training* has been defined as practice on a set of components of a whole task before practice on the whole task. A number of part-task training strategies have been described; their common feature is the division of the whole task into components followed by the training of individual components either separately or in various combinations (Wightman & Lintern, 1985). The major advantage of this class of techniques is that it serves to reduce the magnitude of the processing demands imposed on study participants by the whole task. In turn, the reduction of processing demands has been linked to a more rapid development of skill in the part-task components than might otherwise be achieved if training were accomplished in the context of the whole task (Brown & Carr, 1989; Nissen & Bullemer, 1987; Noble, Trumbo, & Fowler, 1967; Schneider, 1985).

However, there are also a number of potential disadvantages of part-task training, particularly with regard to dual task settings. First, several investigators demonstrated that dual tasks are more than the sum of their component tasks (Bahrick, Noble, & Fitts, 1954; Bahrick & Shelly, 1959; Damos, 1978; Damos & Wickens, 1980). For example, Schneider and Fisk (1982) found continued improvements in dual task performance long after the performance of the constituent single tasks had stabilized. Thus, it appears that there is more to dual task performance than a reduction in the resource demands and subsequent automatization of the single tasks. Second, there appear to be critical attentional-control and task coordination strategies that are not easily acquired during part-task training. Damos and Wickens (1980) found that subjects developed strategies for coordinating two tasks during whole-task training and that these strategies transferred to a different set of tasks. No such transfer was found for part-task training (see also Fabiani et al., 1989; Hunt & Lansman, 1982). Finally, the manner in which part tasks are defined appears to be critical to training success (Wightman & Lintern, 1985). Unfortunately, there is yet no agreed-on method for parsing a whole task into its part-task constituents (but see Fisk, Lee, & Rogers, 1991, for a promising approach).

Whole-task training involves the training of both tasks at the same time. For the most part, this has been accomplished by instructing study participants to treat the two tasks as being of equal importance. The main advantage of this training strategy is that it enables participants to develop task-coordination and attentional-control strategies. As indicated earlier, whole-task training is necessary to reduce the dual task decrements that are found when two tasks are performed together (Damos & Wickens, 1980; Lintern & Wickens, 1991; Schneider & Fisk, 1982). The main disadvantage of whole-task training is that conceivably the processing demands will be so excessive as to prevent participants from learning either of the tasks (Nissen & Bullemer, 1987; Noble et al., 1967).

In summary, it appears that the strength of part-task training is a weakness of whole-task training and vice versa. Thus, the reduction in processing demands associated with training part tasks can lead to automaticity, given the availability of consistent stimulus–response mappings (Kramer, Strayer, & Buckley, 1990; Rogers & Fisk, 1991; Schneider & Shiffrin, 1977), whereas the increased demands associated with whole-task training can slow or prevent learning of the individual tasks. Conversely, task coordination and attentional-control strategies are acquired with the whole-task training strategies but not with the part-task training strategies. Because of the relative strengths and weaknesses of these two strategies, an important question is whether a hybrid part- and whole-task training procedure would promote efficient acquisition and transfer of skill in dual task paradigms.

In fact, a few studies suggested that a *hybrid training strategy* might be effective in dual task settings. Schneider and Fisk (1982) trained study participants on two versions of a visual search task; one version was consistently mapped (CM) and the other variably mapped (VM). Previous studies suggested that, given sufficient practice, participants would eventually become automatized on the CM task (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). This, in fact, occurred in the Schneider and Fisk study. After extensive single task practice on the CM and VM search tasks, participants were required to perform both of the tasks together. Initially, performance declined in the dual task condition relative to the single task condition. However, after study participants were taught to emphasize the VM task rather than the CM task, performance in the dual CM-VM conditions improved to that of the single task baseline conditions. This study suggests that both single task or part-task training and whole-task training are necessary for the acquisition of efficient dual task performance.

Gopher and colleagues (Gopher, 1993; Gopher, Weil, & Siegel, 1989) used another hybrid training strategy. Brickner and Gopher (1981) argued that the advantages of both part-task and whole-task training strategies could be achieved with a training procedure in which participants performed both tasks together (e.g., whole-task training) but varied their emphasis between the two tasks (e.g., part-task training) in different blocks of trials. Thus, in this embedded part- and whole-task training strategy, participants could learn to coordinate and control their attention between the two tasks while still capitalizing on the reduced processing requirements as the priorities were shifted between the two tasks.

In an effort to test this hypothesis, Brickner and Gopher (1981) had participants perform a self-paced letter-typing task with a digit classification task. Six participants were assigned to each of two conditions: a fixed-priority (FP) group, in which the participants were to emphasize both of the tasks equally, and a variable-priority (VP) training group, in which, across different blocks, participants were to vary their priorities between the two tasks. Priorities were indicated by a continuously moving bar graph that was individually scaled on the basis of each participant's performance on a previous block of trials.

Several important results were obtained. First, the VP participants outperformed the FP participants during training. Second, the VP participants were more successful at reducing performance decrements than the FP participants when difficulty of the tasks was varied. Finally, the VP participants' performance was superior to that of the FP participants when participants were transferred to externally paced versions of the two tasks. These results suggest that the acquisition and transfer of dual task skills can be aided by embedding part-task training strategies within the context of the whole task (e.g., VP group) when compared with whole-task training (e.g., FP group). In summary, VP training, a hybrid part- and whole-task training strategy, appears to capitalize on the advantages of the part- and whole-task training procedures without incurring the costs.

Experimental Overview

Although it is clear from the literature just surveyed that we are beginning to explicate some of the important factors that contribute to the successful acquisition, transfer, and retention of skills in dual task settings, there are a number of gaps in our knowledge that require additional research. First, very few studies have examined the efficacy of different dual task training techniques for older adults. As outlined previously here, the hybrid part- and whole-task procedures have shown promise in improving dual task learning and performance. Unfortunately, these techniques have not yet been used with older adults. An important question that we pursue in our study is whether older participants show benefits equivalent to those of younger adults with these techniques. More specifically, we assess the efficacy of VP and FP training techniques for dual task learning and performance.

Second, there have been few attempts, particularly with older adults, to assess the generalizability of dual task or time-sharing skills. Given that the goal of training is usually to support posttraining performance, at least in real world settings, it is quite surprising that the topic of generalizability has not been more thoroughly examined. Although the generalizability of dual task processing or time sharing is a controversial topic (see Ackerman, Schneider, & Wickens, 1984; Brookings & Damos, 1991; Lintern & Wickens, 1991), Gopher and colleagues (Brickner & Gopher, 1981; Gopher et al., 1989) suggested that some training strategies might engender the transfer of time-sharing skills. Studies that have found an association between dual task–processing efficiency and performance in real world skills also suggest that the dual task processing skills might be more general than previously believed (Avolio, Kroeck, & Panek, 1985; Ball & Owsley, 1991; Crosby & Parkinson, 1979; Damos, 1978; Gopher, 1982; North & Gopher, 1976). In any event, the issue of the generalizability of dual task processing skills is important and should be further explored, particularly with respect to aging. In our study, the generalizability of skills learned during training, in the form of transfer to different dual tasks, and resistance to the changes in the difficulty of dual tasks are investigated.

Third, there has been relatively little examination of the qualitative or quantitative changes in processing that occur during dual task practice and training, particularly with older adults. Salthouse and Somberg (1982) provided important information in this regard, at least within the context of a number of separately performed tasks. It appears that older study participants show a similar pattern of changes in the underlying processes during training as younger adults. However, the age-related decrements in performance that were observed early in practice were, for the most part, maintained after extensive practice on the tasks. Fisk and Rogers (1991b) found that age-related decrements in CM memory search performance were eliminated with extensive practice, whereas age-related decrements in CM visual search performance remained after practice. They interpreted these findings as evidence that older adults' ability to form associative connections between stimuli and responses was intact, but they were deficient in their ability to use priority-based learning mechanisms (but see Strayer & Kramer, 1994). Although these results provide valuable information about the changes in information processing that occur during practice for both younger and older adults, they do not address the relative contribution of single task automatization and the learning of dual task processing or task coordination skills to improvements in dual task performance with training.

In an effort to assess the influence of training and age on these components of dual task performance, we had participants train on two tasks—alphabet–arithmetic and monitoring—both together and separately. The alphabet–arithmetic task was chosen because previous studies had found that computation of the answer becomes automatized with practice (Logan, 1988; Rogers & Fisk, 1991; Zbrodoff & Logan, 1986). Thus, the inclusion of this task enabled us to assess the influence of FP and VP training regimens on the automatization of a component of the dual task. One conceivable outcome of the training is that the improvement in dual task performance could be accounted for, in its entirety, by learning and possibly automatization of the single tasks. This single-task learning account of dual task improvement is consistent with a number of theories of skill acquisition that suggest that learning will be specific to the trained tasks (Anderson, 1982; Logan, 1988; Shiffrin & Schneider, 1977). On the other hand, some empirical evidence has suggested that task coordination and dual task processing strategies might be somewhat generalizable, and, therefore, such skills would be expected to transfer to novel tasks (Ackerman et al., 1984; Damos, 1978; Gopher, 1982, 1993; North & Gopher, 1976). Transfer of such a skill will be assessed, as a function of training strategy and age, by requiring participants to perform novel single and dual tasks after training on the monitoring and alphabet–arithmetic tasks. A performance or learning advantage for the VP-trained participants compared with the FP-trained participants when performing the novel tasks would be supportive of the development of a somewhat generalizable task coordination or dual task processing skill.

Method

Participants

Thirty (11 men and 19 women) older and 29 (9 men and 20 women) younger adults participated in the study. The younger participants ranged in age from 18 to 29 years ($M = 20.8$), and the older participants ranged in age from 60 to 74 years ($M = 67.8$). The participants were paid $5.00 per hr for their participation in the study. Half the younger and half the older adults were randomly assigned to the training groups: FP training (15 older and 14 younger participants) and VP training (15 older and 15 younger participants).

All participants were screened for the use of any medication that would influence performance on the experimental tasks (e.g., psychotropic drugs or beta blockers) and for near and far visual acuity. All of the participants possessed corrected visual acuities of at least 20/40. The average corrected acuity of the young and old participants was 20/21.9 and 20/24.8 (Snellen), respectively. These differences were not statistically significant. All of the participants obtained a perfect score on the Ishihara Color Blindness Test (1989).

The participants were administered the Kaufman Brief Intelligence Test (K-Bit; Kaufman & Kaufman, 1990) and the digit span test from the Wechsler Adult Intelligence Scale—Revised (WAIS–R; Wechsler, 1981). The average standardized composite scores for the Kaufman Brief Intelligence Test were 115.6 and 116.3 for the younger and older adults, respectively. This difference was not statistically significant. The average WAIS–R Digit Span scores were 19.4 and 16.7 for the younger and older groups, respectively. Younger adults had a significantly larger digit span than older adults, $F(1, 55) = 7.6, p < .01$.

All of the younger and older participants were also asked to rate their health relative to their age group on a scale of 1 (*excellent*) to 4 (*poor*) and to indicate the number of years of formal education that they received. The groups did not differ on either of these factors. The average health ratings for the younger and older groups were 1.62 and 1.63, respectively. The average years of formal education for the younger and the older groups were 15.5 and 16.0, respectively. Finally, there were no significant differences in any of the intellectual, education, or health variables among members of the same age groups across the two training conditions.

Stimuli and Apparatus

The training and transfer tasks were performed on Dell 386SX computers with VGA monitors. In all cases, the participants responded with keys on the standard PC keyboard. Participants were seated alone in a small, comfortably lit room for each of the experimental sessions. Participants viewed the display from 65 cm. At this distance, the dual task displays (e.g., monitoring and alphabet–arithmetic, scheduling and paired-associates running memory) subtended 15.5 degrees vertically and 20.0 degrees horizontally. Characters in the alphabet–arithmetic and running memory tasks subtended 1.6 degrees vertically and 1.2 degrees horizontally. Individual gauges in the monitoring task were 6.4 degrees in diameter. Feedback bars subtended 0.5 degrees vertically. The horizontal extent of the bars was 6.8 degrees.

Experimental Tasks

Participants were trained with a monitoring task and an alphabet–arithmetic task both separately and together. Participants were then transferred to a scheduling task and a running memory task, which were also performed both separately and together.

Monitoring task. The monitoring task is schematically illustrated in Figure 1. The task required participants to monitor six continuously changing gauges and to reset each gauge as soon as it reached the critical region (e.g., > 9 and in the red region) by pressing one of six keys on a computer keypad. A critical aspect of this task is that the cursors are invisible until sampled. Participants could sample the position of a cursor by pressing one of six keys on the computer keyboard that corresponded to a particular gauge. Only a single gauge (e.g., cursor position) could be sampled at a time. When a gauge was sampled, the cursor position was viewable for 1.5 s. The fact that the position of the cursors on the gauges was not continuously present made it necessary for the participants to construct a mental representation of the dynamics of the movement of the cursors, a relatively difficult and dynamic memory task.

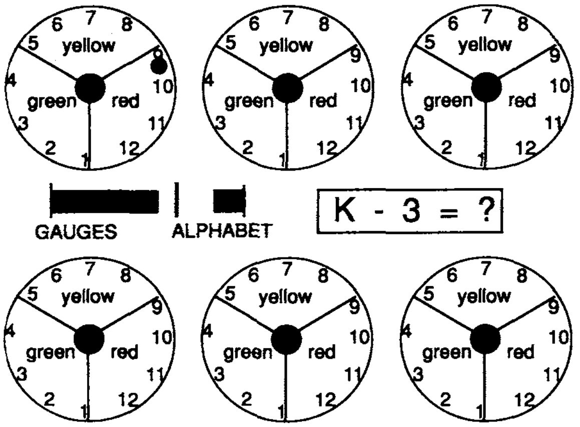

Figure 1. Dual task monitoring and alphabet–arithmetic tasks with feedback bar graphs.

The motion of the cursor on each of the gauges was driven by a variable-rate, pseudorandom forcing function. The motion of the cursors in each column was correlated with a phase offset between the cursor positions. Thus, participants could predict the position of the cursor on one gauge on the basis of the position of the cursor on the other gauge in the same column. The cursors moved in a monotonic fashion and in a clockwise direction. If a participant failed to reset a gauge within 7.5 s after the cursor entered the critical region, the computer reset the gauge, and the event was scored as a miss. Thus, in essence, the monitoring task was force paced. The amount of time required for a cursor to move from the starting point on a gauge to the critical region ranged from 14 to 45 s.

Alphabet–arithmetic task. The alphabet–arithmetic task is also presented in Figure 1 in the form of a particular problem, $K - 3 = ?$ The answer to this problem is H. Participants performed both additions and subtractions with the numbers 2 and 3. Half of the participants performed the task with the first half of the alphabet, whereas the other half performed the task with the second half of the alphabet. In addition to mentally computing the answer to the problem that was presented on the screen, participants were required to compare the answer on the current trial with the response on the previous trial, indicating the greater or lesser letter by typing it on the computer keyboard (e.g., the requirement to indicate the greater or lesser letter varied from trial to trial and was indicated by an upward- or downward-pointing arrow). This task was self-paced. Once participants responded, a new problem appeared on the display within 100 ms. In the present experiment, we were interested in determining whether the VP strategy would lead to better performance and a greater degree of automatization on this task than the FP strategy. The alphabet–arithmetic task was chosen because it provides an opportunity to assess the development of automatic processing as a function of training strategy and age (Logan, 1988).

Scheduling task. The two transfer tasks are illustrated in Figure 2. These tasks were performed in Sessions 7 and 8 by both the FP and VP participants. The scheduling task required participants to assign the incoming box, illustrated in the top left corner of the figure, to one of the four moving lines. The goal of the task was to assign each new box to the line with the smallest total area of boxes. Participants were required to assign boxes as quickly and as accurately as possible. New boxes appeared 2 s after the previous box was assigned by the participant. The difficulty was varied in this task by using a single box height in one condition, boxes with three different heights in another condition, and boxes with five different heights in a third condition. If participants did not assign a box to a line within 7 s, the box was assigned by the computer, and the trial was scored as a miss.

Paired-associates running memory task. The paired-associates running memory task is illustrated in the centrally located box in Figure 2 (e.g., $D = 7$). The participants viewed in a self-paced manner a series of letter–number pairs (e.g., letters A to E and numbers 1 to 8) and were occasionally probed to indicate whether a letter–number pair matched the last presentation of the pair (e.g., $D = 7$?). The response probes occurred every four to seven presentations of the letter–number pairs. The participants pressed one key on the computer keyboard if the pair matched the previous presentation of this pair and another key if it did not match the last presentation. The association between particular letters and numbers changed over presentations. Task difficulty was varied with the letters *A–C, A–D,* and *A–E* for the easy, medium, and difficult conditions, respectively.

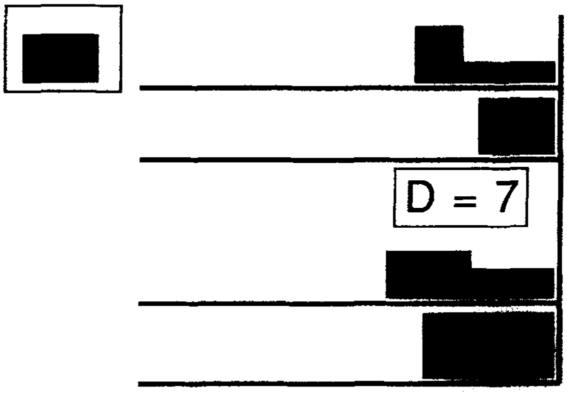

Figure 2. Dual task scheduling and running memory tasks that were performed by the participants in the transfer phase of the study.

Procedure

The procedure is outlined in Table 1. In all experimental sessions, trial blocks were 5 min long. Feedback on average RT and accuracy was provided after each block of trials. Continuous feedback was also provided during training.

Introductory testing and pretraining. In Session 1, participants were given a tour of the laboratory facilities and provided information on the types of activities in which they would participate. Participants were then administered a number of the pencil-and-paper tests including the K-Bit, Digit Span, and Ishihara Color Blindness Test. Participants also completed a demographic questionnaire at this time and completed the near and far visual acuity tests. This session lasted approximately 1 hr. Participants were randomly assigned to experimental groups, FP and VP training at this time.

Participants performed both the monitoring and alphabet–arithmetic tasks during Sessions 2 and 3. In Session 2, participants practiced the monitoring and alphabet–arithmetic tasks alone. The experimenter first demonstrated each of the tasks to the participants. These demonstrations lasted 90 s for each of the tasks. All of the cursors were visible during the demonstration. Participants then performed four 5-min blocks of the monitoring and alphabet–arithmetic tasks. Session 2 lasted approximately 1 hr. In Session 3, participants performed both single and dual task versions of the monitoring and alphabet–arithmetic tasks. Participants began by performing four single task blocks each of the monitoring and alphabet–arithmetic tasks. Participants then performed six 5-min dual task blocks. This session lasted approximately 1½ hr. Participants were given brief rest breaks between each of the trial blocks.

Table 1
An Overview of the Conditions and Their Durations for Each of the Experimental Sessions

Session	Description
	Preliminary testing
Session 1	Demographic questionnaire, vision testing, cognitive testing
Session 2	One 90-s demonstration of the monitoring and alphabet–arithmetic tasks Four 5-min single task blocks of monitoring and alphabet–arithmetic tasks
Session 3	Four 5-min blocks for single task monitoring and alphabet–arithmetic tasks Six 5-min blocks for dual task monitoring and alphabet–arithmetic tasks
	Fixed- and variable-priority training
Sessions 4–6	Ten 5-min blocks for dual task monitoring and alphabet–arithmetic tasks Two 5-min blocks for single task monitoring and alphabet–arithmetic tasks
	Transfer
Sessions 7–8	One 5-min block of each task (scheduling and running memory) in easy, medium, and difficult conditions Four 5-min blocks of dual task scheduling and running memory tasks with easy–hard, hard–easy, and medium–medium difficulty pairings

FP and VP training. In Sessions 4 through 6, participants were given continuous feedback in the form of a bar graph (see center left in Figure 1) indicating their current performance (last five responses) on each task relative to their single-task RT and accuracy performance from the previous session. Participants were instructed to perform the task so as to keep each of the task feedback bars against the central vertical line. Participants were also provided with feedback on their performance across the entire block at the end of each 5-min block of trials.

For participants in the FP training group, equal priority was placed on both tasks at all times (e.g., the vertical line in the feedback display was located equidistant from the monitoring and alphabet bars). For participants assigned to the VP training group, the priority placed on each task in the dual task conditions was varied between blocks such that participants were required to emphasize their performance differentially on the two tasks. Five different processing priorities were used in the VP training condition: 20–80, 35–65, 50–50, 65–35, and 80–20 for the alphabet–arithmetic and monitoring tasks, respectively. The vertical line in the feedback display was adjusted to reflect the task priorities in each block of trials. Thus, for example, in the 20–80 condition, the vertical line would be closer to the low-priority task (e.g., 20% of the distance between the low- and high-priority tasks) than to the high-priority task. As indicated previously here, the feedback that participants received was based on their own performance in the previous block of trials. The feedback indicator represented a composite of speed and accuracy scores such that participants were required to achieve 80% of their previous single-task accuracy in each of the dual task priority conditions. Speed criteria were adjusted such that in the 20% priority condition participants were required to respond faster than the 80th percentile of their previous single-task RT distribution for the same task. For the 50% emphasis condition, participants were required to respond faster than the 50th percentile of their previous single-task RT distribution for the same task. Thus, in essence, this criterion took into account the entire distribution of RTs as well as the average accuracy in a recent block of single task trials in setting the desired performance for the participants in each block of dual task trials.

During each session of training, participants performed ten 5-min blocks of dual task trials and two 5-min blocks of the alphabet–arithmetic and monitoring tasks. The single-task blocks for both of the tasks were performed after the dual task blocks. The order of the single task blocks was counterbalanced across sessions and subjects. Participants in the VP training group performed two dual task blocks at each of the five emphasis conditions. The order of these blocks was counterbalanced across sessions and subjects. Participants in the FP conditions performed all dual task blocks at 50–50 priority. Each of the training sessions lasted approximately 1½ hr. Participants were given brief rest breaks between each of the blocks.

Transfer sessions. In Sessions 7 and 8, participants transferred to the scheduling and running memory tasks (see Figure 2). These tasks were performed both alone and in dual task conditions at three different levels of difficulty. Continuous feedback was not presented in these sessions, but participants were asked to perform the tasks as well as possible. Participants received feedback on their accuracy and average RT after each block of trials. In each session, participants performed one 5-min block of each of the two tasks at each of three difficulty levels. Participants also performed four 5-min dual task blocks at each of three difficulty levels. Each transfer session lasted approximately 1½ hr. Participants were given brief rest breaks between each of the blocks of trials.

Results and Discussion

In this section, we first describe the analyses that we performed on the RT and accuracy data collected in the pretraining sessions. These data are analyzed to verify that the VP and FP participants exhibited similar performance before the introduction of the training intervention. These data will also establish any age-related differences in single- and dual task performance before formal training. Second, we present the data obtained during the three sessions that constituted the training intervention (e.g., Sessions 4 through 6). These data enable us to determine the relative benefits of FP versus VP training on the trained tasks for both the younger and older participants. Finally, we present the data from the last two sessions (e.g., Sessions 7 and 8) to assess the effects of training strategy and age on the transfer to novel tasks.

Pretraining: Session 3

The RT and accuracy data were submitted to three-way analyses of variance (ANOVAs) with age (young and old) and training group (FP and VP) as between-groups factors and task condition (single and dual tasks) as a within-subjects factor.[1] Significant main effects were obtained for both age, $F(1, 57) = 5.2$, $MSE = 33{,}927$, $p < .05$, and task condition, $F(1, 57) = 62.9$, $MSE = 43{,}439$, $p < .01$, for RT in the monitoring task. Older adults responded more slowly than younger adults, and the single-task version of the monitoring task was performed more quickly than the dual task version. There was also a significant interaction between task condition and age, $F(1, 57) = 4.3$, $MSE = 24{,}924$, $p < .05$. The increase in RT from the single to dual task conditions was 341 ms for the younger adults and 423 ms for the older adults. The accuracy effects mirrored those obtained for RT. Main effects were obtained for age, $F(1, 57) = 64.1$, $MSE = 0.101$, $p < .01$, and task condition, $F(1, 57) = 94.9$, $MSE = 0.093$, $p < .01$. Younger adults were more accurate than older adults, and the single task version of the monitoring task was performed more accurately than the dual task version. A significant two-way interaction between age and task condition, $F(1, 57) = 5.7$, $MSE = 0.034$, $p < .05$, was obtained and indicates that older adults were more penalized by performing in the dual task conditions than were younger subjects. The decrease in accuracy from single- to dual task conditions was 13.1% for the younger subjects and 19.5% for the older adults.

The effects obtained in the pretraining session for the alphabet–arithmetic task were much like those found for the monitoring task. Older adults were slower, $F(1, 57) = 61.9$, $MSE = 129{,}471$, $p < .01$, and less accurate, $F(1, 57) = 22.2$, $MSE = 0.092$, $p < .01$, than younger adults. Single-task performance was faster, $F(1, 57) = 72.2$, $MSE = 130{,}891$, $p < .01$, and more accurate than dual task performance, $F(1, 57) = 14.2$, $MSE = 0.017$, $p < .01$. Finally, there was a significant two-way interaction between task condition and age, $F(1, 57) = 14.0$, $MSE = 25{,}549$, $p < .01$, for RT. The increase

---

[1] All RTs presented in the tables are means of the single subject median RTs. Median RTs were analyzed in all of the ANOVAs. All post hoc comparisons are performed with Bonferroni t tests and are significant at $p < .05$.

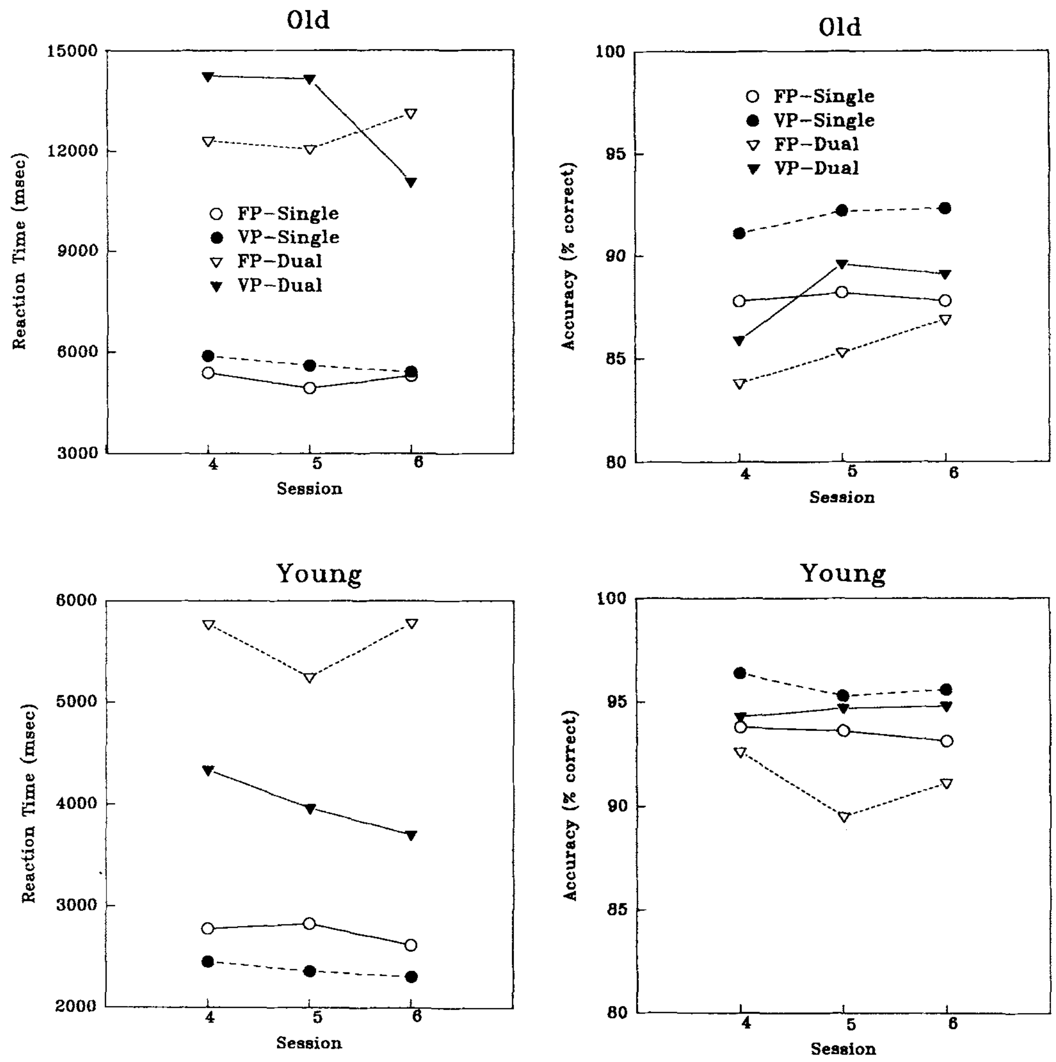

Figure 3. Single and dual task reaction time and accuracy data from Sessions 4, 5, and 6 (training) for the fixed-priority (FP) and variable-priority (VP) participants in the alphabet–arithmetic task. Note that the range of reaction time values on the ordinate differs for the younger and older adults.

in RT from the single to the dual task conditions was 1,952 ms for the younger participants and 7,240 ms for the older participants.

To summarize the pretraining effects, we found older participants were generally slower and less accurate than younger participants. The older adults also showed larger performance decrements from single to dual task conditions than younger participants. Finally and perhaps most importantly, there was no main effect of training condition or interaction of this factor with age or task condition. Thus, we can safely assert that performance of the VP and FP groups was not statistically different before the training intervention.

FP and VP Training: Sessions 4 to 6

The RT and accuracy data for the single and dual task conditions for the younger and older participants are presented in Figure 3 for the alphabet–arithmetic task and in Figure 4 for the monitoring task. It is important to note that the comparison of training efficacy for the FP and VP strategies in the dual task conditions is performed

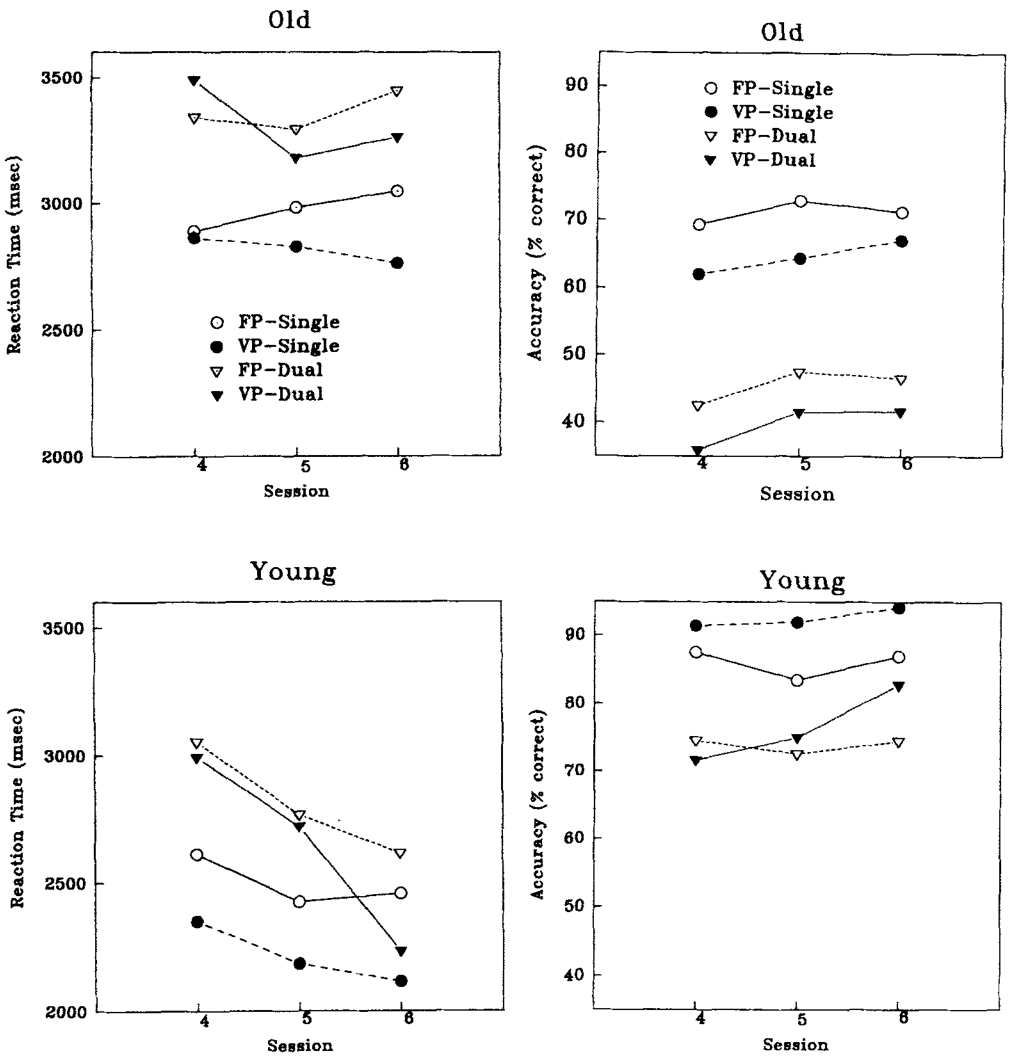

Figure 4. Single and dual task reaction time and accuracy data from Sessions 4, 5, and 6 (training) for the fixed-priority (FP) and variable-priority (VP) participants in the monitoring task.

on the 50–50 dual task emphasis blocks. This is necessary because emphasis and processing priority is equated across the two training conditions in these blocks. However, this might put VP participants at a disadvantage because they received 80% fewer trials in the 50–50 conditions than the FP participants (e.g., the VP participants performed the same number of practice trials as the FP participants but across five different dual task priority levels).

Alphabet–arithmetic task. The RT and accuracy data obtained in the alphabet–arithmetic task were submitted to four-way ANOVAs with age (young and old) and training group (FP and VP) as between-groups factors and session (4 through 6) and task condition (single and dual) as within-subjects factors. Significant main effects were obtained for age, $F(1, 57) = 39.7$, $MSE = 137{,}647$, $p < 0.01$, task condition, $F(1, 57) = 53.7$, $MSE = 166{,}833$, $p < .01$), and session, $F(2, 114) = 7.6$, $MSE = 163{,}123$, $p < .01$. Younger participants responded more quickly than older ones. The single task version of the alphabet–arithmetic task was performed more rapidly than the dual task version. RTs decreased with practice.

The main effects were qualified by a number of significant higher order interactions. Consistent with pretraining, task condition interacted with age, $F(1, 57) = 5.5$, $MSE = 172{,}140$, $p < .05$, such that older participants displayed a larger dual task RT cost (7,414 ms) than younger participants (2,244 ms). The size of the dual task RT cost was influenced for both younger and older participants by practice and training condition (Session × Task Condition × Training Condition), $F(2, 114) = 6.7$, $MSE = 103{,}687$, $p < .01$. The increase in RT from the single to the dual task version of the alphabet–arithmetic task in the first session of training was 4,960 ms for the FP training group and 5,123 ms for the VP training group. The comparable RT costs in the last training session were 5,500 ms for the FP group and 3,538 ms for the VP group. Thus, although the dual task performance improved relative to single task performance with VP training, there was no substantial improvement in dual task performance with FP training. Finally, a significant four-way interaction was obtained among the age, training condition, task condition, and session factors, $F(2, 114) = 5.1$, $MSE = 66{,}505$, $p < .01$. Performance in the VP dual task condition improved in a uniform fashion across the training sessions for the younger adults, resulting in a decrease in RT of 483 ms. On the other hand, the older VP adults showed a larger total improvement in dual task performance (e.g., 2,687 ms), but this improvement occurred in the last training session.

Three significant main effects were obtained for accuracy. Younger participants were more accurate than older participants, $F(1, 57) = 21.9$, $MSE = 0.055$, $p < .01$. Accuracies were higher in the single-task than in the dual task conditions, $F(1, 57) = 10.5$, $MSE = 0.015$, $p < .01$. Performance was more accurate with VP training than with FP training, $F(1, 57) = 6.3$, $MSE = 0.0013$, $p < .05$. There was also a significant interaction between session and age, $F(2, 114) = 9.5$, $MSE = 0.015$, $p < .01$, indicating that accuracy increased with practice for older adults but not for younger adults.

To summarize the training effects in the alphabet–arithmetic task, we found that VP training improved performance for both younger and older subjects, particularly in the dual task conditions. Furthermore, the absolute improvement in response speed in the dual task conditions was substantially larger for the older than for the younger participants with VP training. Thus, it appears that the older adults can benefit as much as, if not more than, younger adults by VP training. Improvements in performance in the FP training conditions were confined to the single tasks for both the younger and older participants.

One interesting issue to address is the nature of learning that has occurred as a function of training. Given that the stimuli and responses are consistently mapped in the alphabet–arithmetic task, we ask whether VP training led to more automatic processing than FP training. Automatization has been evaluated within the alphabet–arithmetic task by assessing both overall improvement in the speed of performance and the slope of the addend–subtrahend function with practice (Logan, 1988; Rogers & Fisk, 1991; Zbrodoff & Logan, 1986). With respect to the absolute speed improvement criterion, it is clear that VP training is superior to FP training. An analysis of changes in the addend–subtrahend slope (e.g., add or subtract 2 or 3 from the letters in the present study) also suggested that VP training led to more automatic performance than FP training. The slopes for the younger adults in the FP and VP training conditions in the first session of training were 620 and 634 ms, respectively. The comparable slopes for the younger adults in the last session of training were 479 and 176 ms. The slopes for the older adults in the FP and VP conditions in the first session of training were 1,039 and 1,105 ms, respectively. The comparable slopes in the last training session were 704 and 272 ms, respectively. Thus, the decreases in the slopes as a function of training were significantly larger for the VP than for the FP training conditions for both the younger and older adults, $F(2, 114) = 10.6$, $MSE = 13{,}986$, $p < .01$.

It should be noted that the development of automaticity in the alphabet–arithmetic task may not account for the entirety of the performance improvement with VP training. Thus, it is conceivable that participants learned dual task processing strategies in addition to improving their performance on each task. Models of skill acquisition and automaticity suggest that learning will be specific to the trained tasks (Anderson, 1982; Logan, 1988; Shiffrin & Schneider, 1977). Therefore, these models predict poor transfer to novel tasks. On the other hand, some evidence suggests that dual task processing strategies are somewhat generalizable (Ackerman et al., 1984; Damos, 1978; Gopher, 1982; North & Gopher, 1976), and, therefore, such strategies would be expected to transfer to novel tasks. These predictions are examined in the analysis of the transfer data.

Monitoring task. The RT and accuracy data obtained in the monitoring task during training are presented in Figure 4. Three main effects were obtained for RT. Older adults responded more slowly than younger adults, $F(1, 57) = 7.5$, $MSE = 87{,}234$, $p < .01$. Single task conditions were performed more quickly than dual task conditions, $F(1, 57) = 43.3$, $MSE = 24{,}905$, $p < .01$. Response speed improved with practice, $F(2, 114) = 22.5$, $MSE = 26{,}594$, $p < .01$. The main effects were qualified by two significant interactions. Younger participants benefited more from practice than did older adults, $F(2, 114) = 7.4$, $MSE = 87{,}234$, $p < .01$. Performance improved to a greater extent with VP training than with FP training, $F(2, 114) = 5.4$, $MSE = 50{,}570$, $p < .01$. The average improvements in performance with VP and FP training between Sessions 4 and 6 were 330 and 81 ms, respectively.

Three main effects were obtained for accuracy in the monitoring task. Older adults were less accurate than younger adults, $F(1, 57) = 16.9$, $MSE = 0.043$, $p < .01$. Performance was more accurate in the single task than in the dual task conditions, $F(1, 57) = 51.7$, $MSE = 0.021$, $p < .01$. Finally, accuracy improved with practice, $F(2, 114) = 15.2$, $MSE = 0.034$, $p < .01$.

Consistent with the data obtained in the alphabet–arithmetic task, participants benefited to a greater extent with VP than with FP training. Interestingly, however, training condition did not interact with task condition. Thus at first glance, it appears that the VP training benefit is not confined to the dual task conditions as was the case for the alphabet–arithmetic task. However, the failure to find specificity of the VP training effect is not particularly surprising if one considers the structural differences between the alphabet-arithmetic and monitoring tasks. The alphabet–arithmetic task involves the computation or retrieval of a single piece of information. On the other hand, the monitoring task involves keeping track of several distinct and dynamic information sources. Thus in essence, monitoring might be considered to represent a dual or multitask in and of itself.

In summary, all of the training effects that were observed for the monitoring and alphabet–arithmetic tasks were in favor of the VP training strategy. This is actually quite impressive given the fact that participants in the VP training conditions had 80% fewer practice trials in the 50–50 emphasis condition that was used as the basis for the FP-VP comparison.

VP training strategy. The analyses described previously suggest that the VP training strategy was effective in improving dual task learning and performance on the monitoring and alphabet–arithmetic tasks. However, thus far, we have not provided any formal analysis of the extent to which the younger and older adults were able to vary their processing priorities between the two tasks during VP training. Figure 5 illustrates that both younger and older participants were, in fact, able to vary their processing priorities as instructed. This performance operating characteristic (POC) figure presents the cross-plotted standardized alphabet–arithmetic RT and monitoring accuracy

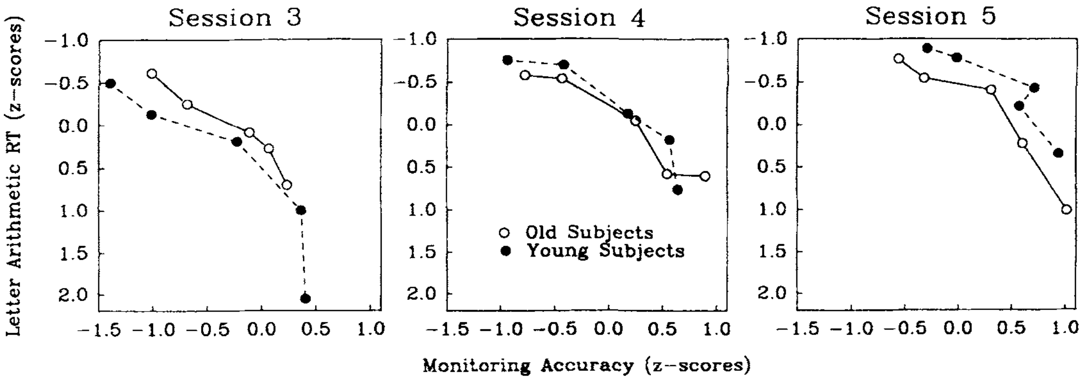

Figure 5. Performance operating characteristics for young and old variable-priority participants in Sessions 3, 4, and 5. (RT = reaction time.)

scores for the younger and older participants across the three training sessions.[2] Scale values at the bottom left of the figure represent poor performance; scale values that converge at the top right of the figure represent good performance.

These data were analyzed in two different ways. First, we compared the younger and older adults on a measure of the maximum performance change, across the five dual task priority conditions, for the standardized alphabet–arithmetic RT and monitoring accuracy data. The maximum performance change measure was derived by subtracting performance on the 20–80 condition from performance on the 80–20 condition separately for the alphabet–arithmetic and the monitoring tasks. These data were then submitted to ANOVAs with age group as a between-subjects factor and session as a within-subjects factor. Main effects were obtained for age, $F(1, 57) = 11.8$, $MSE = 10.6$, $p < .01$, and session, $F(2, 114) = 4.7$, $MSE = 4.1$, $p < .05$, for alphabet–arithmetic RT. These main effects were qualified by a significant two-way interaction between age and session, $F(2, 114) = 10.7$, $MSE = 9.3$, $p < .01$, such that the difference between the older and younger adults on the measure of maximum performance change decreased with practice. Post hoc comparisons revealed that the age differences were significant only in Session 1 ($p < .05$). In Session 1, the older adults showed less of a performance change between the 80–20 and 20–80 conditions than the younger participants in both the alphabet–arithmetic and monitoring tasks. However, older and younger participants showed statistically equivalent performance changes in Sessions 4 and 5 ($p > .65$). None of the main effects or interaction was significant for the monitoring accuracy measure.

In a second analysis, we compared the rank order of the five priority conditions between the younger and older groups. Thus, these analyses enabled us to determine the extent to which the younger and older participants followed instructions to vary their processing priorities in a systematic fashion across the five dual task conditions. In this case, the standardized scores for each participant from the five priority conditions were rank ordered and a percentage correct score was derived. Participants received a score of 1.0 if their performance scores corresponded to the priority instructions and correspondingly lower accuracy scores depending on the degree of mismatch between their performance scores and the instructions. These accuracy scores were then submitted to ANOVAs with age as a between-groups factor and session as a within-subjects factor. None of the main effects or interaction attained statistical significance for either the monitoring accuracy or alphabet–arithmetic RT analyses. In summary, the analyses of both the maximum performance change and rank-order data suggest that both older and younger adults were able to use the instructions and performance feedback effectively (e.g., in the form of the bar graphs) to vary their processing priorities between the two tasks.

Transfer: Sessions 7 and 8

The RT data for the single and dual task conditions for the younger and older participants are presented in Figure 6 for the scheduling task and Figure 7 for the paired-associates task. The accuracy data are presented in Tables 2 and 3.

Scheduling task. The RT and accuracy data obtained in the scheduling task were submitted to five-way ANOVAs with age (young and old) and training group (FP and VP) as between-groups factors and session (7 and 8), task condition (single and dual), and box size (1, 3, and 5) as within-subjects factors. Significant main effects were obtained for age, $F(1, 57) = 5.1$, $MSE = 654{,}348$, $p < .05$, task condition, $F(1, 57) = 6.6$, $MSE = 388{,}530$, $p < .01$, and session, $F(2, 114) = 27.3$, $MSE = 341{,}398$, $p < .01$. Younger adults responded more quickly than older adults. RTs were faster with practice, and responses in the single-task conditions were quicker than those in the dual task conditions.

These main effects were qualified by a number of significant interactions. Training condition interacted with box size, $F(2, 114) = 6.1$, $MSE = 826{,}544$, $p < .01$, such that the difference in RTs in

---

[2] We could have presented four different POCs because both accuracy and RT data were collected in both the alphabet–arithmetic and monitoring tasks. However, in examining the POCs, it became clear that participants chose to vary their RT in the arithmetic task in response to priority instructions while holding accuracy relatively constant. In the monitoring task, participants varied their accuracy while holding their RT relatively constant. Therefore, we decided to confine our analysis and presentation of the data to the alphabet–arithmetic RT and monitoring accuracy data. However, POCs for the other dependent variables are available on request.

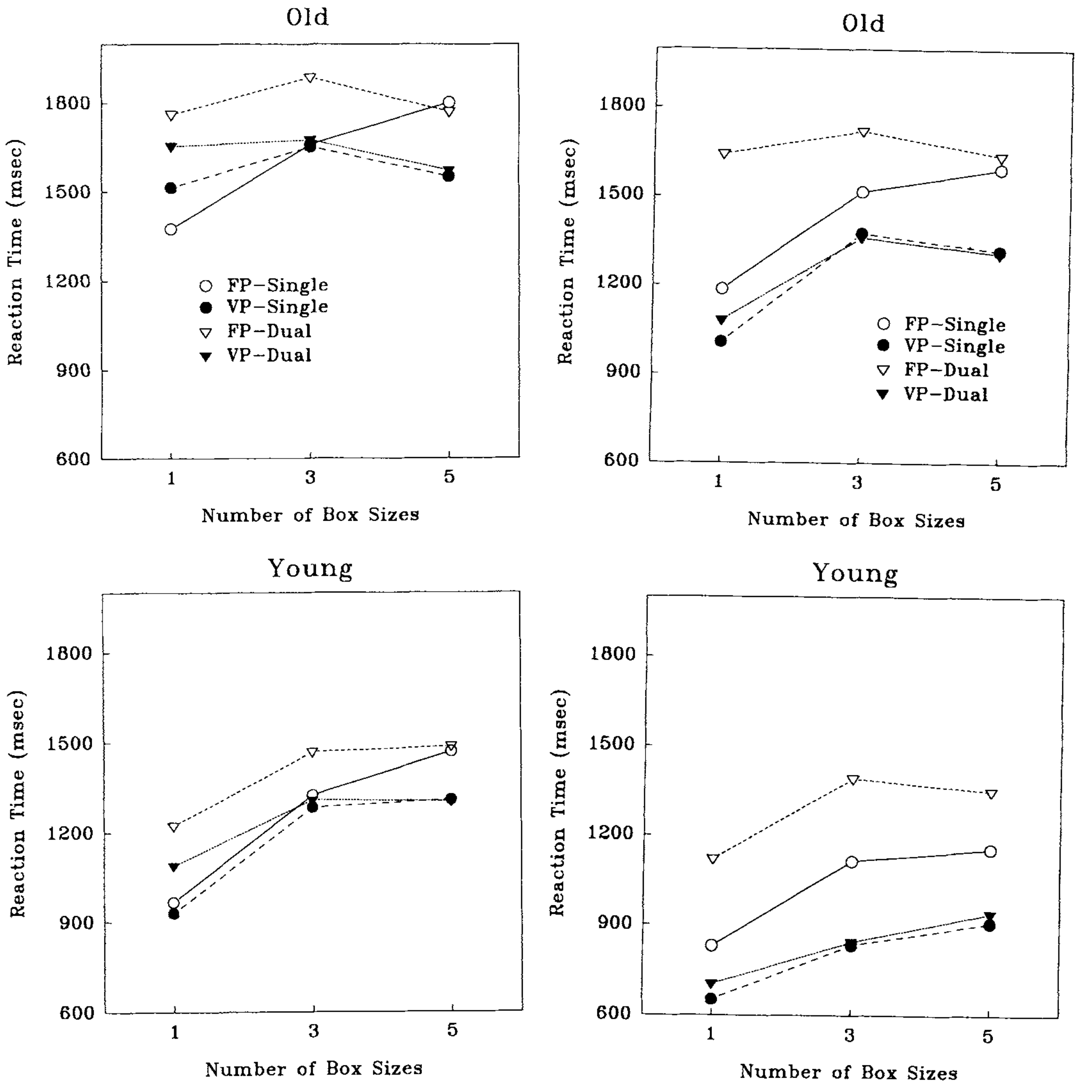

Figure 6. Single- and dual task reaction time data from Transfer Sessions 7 (A) and 8 (B) for the fixed-priority (FP) and variable-priority (VP) participants in the scheduling task.

the VP and FP conditions increased with the number of box sizes that participants were required to assign to the moving lines. Training condition also interacted with task condition, $F(1, 57) = 9.7$, $MSE = 604{,}174$, $p < .01$. The difference between single and dual task conditions was larger for the FP (206 ms) than for the VP participants (43 ms). In fact, post hoc comparisons revealed a significant difference between single and dual task RTs for the FP subjects but not for the VP subjects.

A significant three-way interaction was obtained among the training, task condition, and box size factors, $F(1, 57) = 9.2$, $MSE = 448{,}285$, $p < .01$. The VP participants responded significantly more quickly than the FP participants in all conditions except the single task versions of the small and intermediate box size conditions. Finally, a significant four-way interaction was obtained among the session, task condition, training, and box size factors, $F(2, 114) = 10.1$, $MSE = 570{,}504$, $p < .01$. Dual task–processing deficits, in the form of longer RTs in the dual task condition compared with the single task condition, decreased as a function of

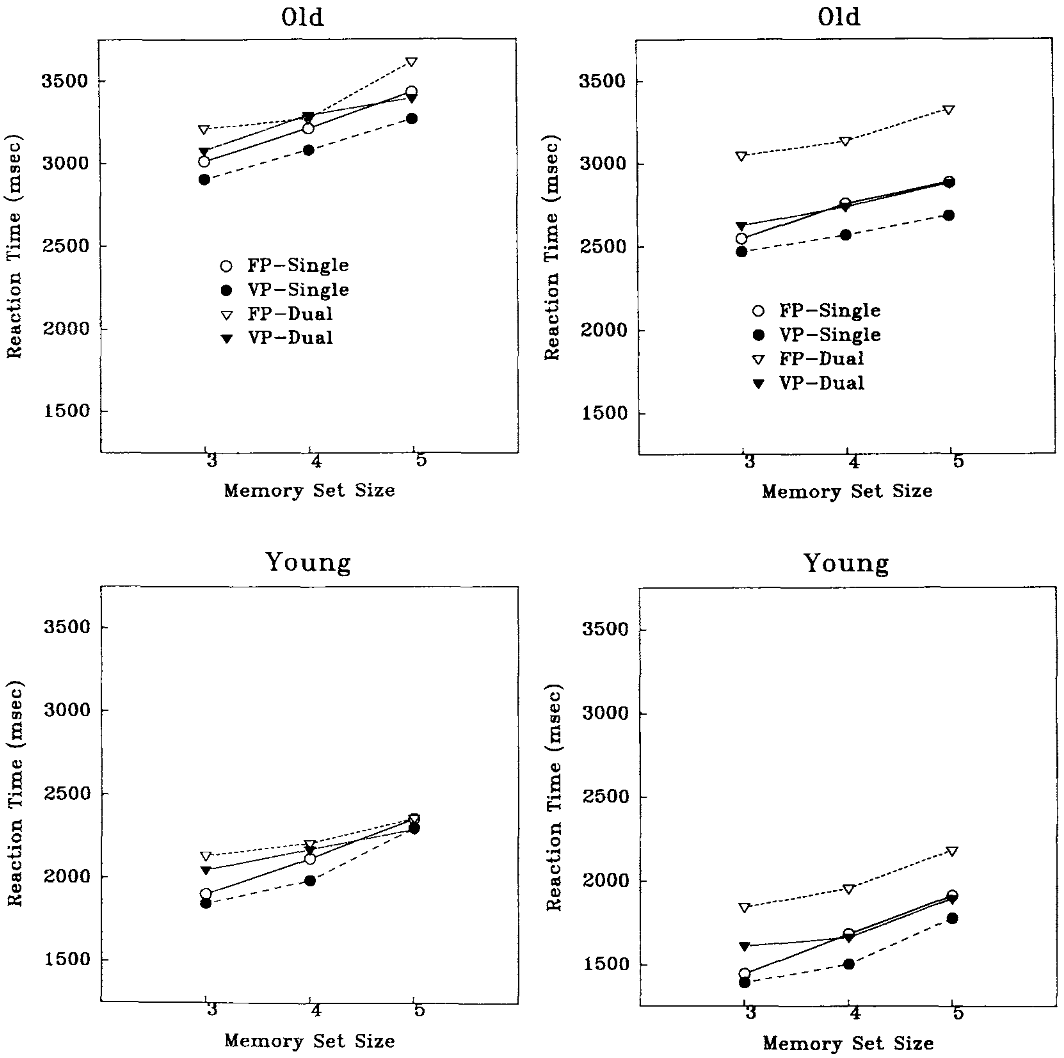

Figure 7. Single- and dual task reaction time data from Transfer Sessions 7 (A) and 8 (B) for the fixed-priority (FP) and variable-priority (VP) participants in the paired-associates running memory task.

practice to a greater degree for the VP than for the FP participants in the box sizes 1 and 3 conditions.

Two main effects were obtained for the accuracy variable in the scheduling task. Accuracy improved with practice, $F(2, 114) = 6.0$, $MSE = 0.055$, $p < .01$, and accuracy decreased from the box size 1 condition to the box sizes 3 and 5 conditions, $F(2, 114) = 8.1$, $MSE = .091$, $p < .01$.

To summarize the performance effects in the scheduling task, we found that the RT data clearly suggest a transfer advantage for those participants trained with the VP strategy. The training strategy benefits were most apparent in the dual task versions of the task. Participants trained with the VP strategy were also able to take better advantage of practice to improve their RTs, particularly in the dual task versions of the scheduling task. It is also important to note that both age groups benefited equivalently from the VP training. Thus, these data suggest that subjects learned a generalizable dual task processing skill during the three sessions of training.

Paired-associates running memory task. The RT and accuracy data obtained in the paired-associates task were submitted to five-way ANOVAs with age (young and old) and training group (FP

Table 2
Single and Dual Task Accuracy (Percentage Correct) Data From Transfer Sessions 7 and 8 for FP and VP Participants in the Scheduling Task

Training group/session	Task condition/Box sizes					
	Single			Dual		
	1	3	5	1	3	5
Younger group						
FP 7	86.5	61.2	64.0	80.3	64.5	65.6
FP 8	87.0	65.5	66.7	82.1	63.8	68.1
VP 7	88.3	60.6	61.1	83.4	65.3	63.6
VP 8	89.4	63.6	69.2	83.6	61.6	65.5
Older group						
FP 7	71.9	56.3	58.1	61.4	55.1	55.8
FP 8	79.3	62.6	64.8	73.1	61.9	62.1
VP 7	80.0	60.3	61.6	74.9	63.2	64.4
VP 8	84.9	63.6	66.3	79.7	63.5	64.7

Note. FP = fixed priority; VP = variable priority.

and VP) as between-groups factors and session (7 and 8), task condition (single and dual), and number of letters (3, 4, and 5) as within-subjects factors. Main effects were obtained for the session, $F(2, 114) = 13.9$, $MSE = 110{,}832$, $p < .01$, difficulty, $F(2, 114) = 3.2$, $MSE = 340{,}386$, $p < .05$, and age, $F(1, 57) = 4.3$, $MSE = 179{,}592$, $p < .05$, factors. Performance improved with practice. RT increased with increases in the number of letter–number pairs, and older adults responded more slowly than younger adults.

Table 3
Single and Dual Task Accuracy (Percentage Correct) Data From Transfer Sessions 7 and 8 for FP and VP Participants in the Paired-Associates Running Memory Task

Training group and session	Task condition/Number of letters					
	Single			Dual		
	3	4	5	3	4	5
Younger group						
FP 7	92.1	89.0	80.2	85.1	81.9	79.9
FP 8	95.3	87.6	89.8	89.0	84.5	83.5
VP 7	96.3	91.5	89.9	89.8	88.5	82.0
VP 8	96.9	90.9	91.1	88.1	88.7	83.2
Older group						
FP 7	84.1	74.3	68.6	76.5	72.3	64.6
FP 8	78.5	79.4	76.2	75.6	72.1	61.1
VP 7	81.1	73.9	71.5	84.3	77.7	76.2
VP 8	85.4	87.9	80.1	85.0	84.4	76.2

Note. FP = fixed priority; VP = variable priority.

Significant two-way interactions were obtained for training and task condition, $F(1, 57) = 5.7$, $MSE = 340{,}362$, $p < .05$, and training and session, $F(2, 114) = 5.8$, $MSE = 457{,}462$, $p < .01$. The single to dual task RT cost was larger for the FP (252 ms) than for the VP participants (159 ms). Participants trained with the VP strategy showed a more substantial improvement in RT with practice than those trained with the FP strategy (e.g., 242 ms for VP participants and 98 ms for FP participants). Finally, a significant three-way interaction was obtained among the training, sessions, and task condition factors, $F(2, 114) = 5.2$, $MSE = 310{,}707$, $p < .01$. Improvements in RT as a function of practice were equivalent for the VP and FP participants in the single task conditions (499 ms for the VP and 468 ms for the FP participants). However, VP participants showed a substantially larger improvement in RT with practice in the dual task conditions (477 ms for VP and 219 ms for FP participants).

Three main effects were obtained for accuracy in the paired-associates task. Accuracy decreased with increases in the number of letter–number pairs, $F(2, 114) = 4.3$, $MSE = 0.166$, $p < .01$. Accuracy was higher for the VP than for the FP participants, $F(1, 57) = 8.1$, $MSE = 0.208$, $p < .01$ and the young adults were more accurate than the older adults, $F(1, 57) = 4.7$, $MSE = 0.035$, $p < .05$.

To summarize the performance effects in the paired-associates running memory task, we found that VP participants outperformed FP participants in both RT and accuracy. Like the results in the scheduling task, the VP performance advantages were mostly confined to the dual task conditions. Thus, these data lend additional support to our argument that participants learned a generalizable dual task processing skill during their initial training.

General Discussion

Several important findings were obtained in the present study. First, our results clearly suggest that VP training can be effectively used in tasks with substantial memory demands. As previously discussed, Gopher and colleagues (Brickner & Gopher, 1981; Gopher, 1993; Gopher et al., 1989) have confined their examination of the utility of the VP training strategy to tasks that are primarily psychomotor in nature. In three of four of our tasks, participant learning and performance depended on the ability to encode and rapidly retrieve information from both short-term (e.g., paired-associates running memory task and monitoring task) and long-term (e.g., alphabet–arithmetic and monitoring tasks) memory. Thus, it appears that VP training may be applicable to a wider range of tasks than previously demonstrated.

Second, our results suggest that the VP processing benefits in terms of both the rate of learning and the level of mastery achieved during training were the result of both automatization of single task components of the dual tasks, as well as the acquisition of a generalizable task coordination or management skill. The large decrease in the addend–subtrahend slope in the alphabet–arithmetic task with VP training is consistent with the development of automatic processing in this task (Logan, 1988; Rogers & Fisk, 1991; Zbrodoff & Logan, 1986). However, there was also abundant evidence to suggest that the learning engendered by the VP training strategy was not confined to the single task components of the dual tasks. VP training benefits were larger in the dual-task condition than in the single task condition for both the training and the transfer tasks. More important, the VP learning and performance benefits that were observed during training were transferred to novel tasks. This finding is consistent with the development of a generalizable task coordination skill (Ackerman et al., 1984; Brookings & Damos, 1991; Lintern & Wickens, 1991). Of course, the determination of the limits of the generalizability of this skill awaits further experimentation with a wider range of tasks and processing components.

As previously discussed, older adults appear to be particularly disadvantaged when required to redeploy attention rapidly and strategically among several concurrently performed tasks (Hawkins et al., 1992; Korteling, 1991; McDowd et al., 1991). Thus, one of our original goals was to determine the extent to which older adults would benefit from dual task training strategies that emphasized flexible processing. The results obtained in the training and transfer phases of our study clearly suggest that older adults benefit at least to the same extent as younger adults from a training strategy that emphasizes varying processing priorities between concurrently performed tasks. Our findings are mixed, however, with respect to the question of whether dual task training can narrow the age-related gap in dual task performance that has been exhibited in numerous studies (Crossley & Hiscock, 1992; Korteling, 1991, 1993; Lorsbach & Simpson, 1988; McDowd & Craik, 1988; Park et al., 1989; Ponds et al., 1988; Salthouse et al., 1984). The older adults in our VP training group showed substantially greater learning in the dual task conditions of the alphabet–arithmetic task than did the younger VP participants. On the other hand, the young adults in the VP training group showed more learning in the dual task conditions of the monitoring task than did the older VP participants. It is interesting to note, however, that we did not find a significant age-related dual task deficit for either of the transfer tasks. Thus, although our results do not provide an unequivocal answer to the question of whether age-related differences in dual task performance can be reduced or eliminated through training, they do suggest that these performance decrements may be reduced under some conditions.

Implications for Models of Aging and Information Processing

Earlier, we discussed several models that have been proposed to account for age-related differences in dual task performance. The complexity model proposed by McDowd and Craik (1988) suggests that older adults should be proportionally slower than younger adults as the complexity of the tasks being performed increases, regardless of whether the tasks are performed in a single or dual task paradigm. Thus, within the complexity model, dual tasks represent nothing more than complex versions of single tasks.

Two aspects of our data are inconsistent with the predictions of the complexity model. First, the differential rates of learning obtained during our training intervention appear to be inconsistent with the proposal that dual tasks represent nothing more than complex versions of single tasks. If this were the case, we would expect equivalent proportional training benefits for both single and dual tasks. However, our VP training strategy was significantly more effective in improving performance across three sessions of training in the dual task version than in the single task version of the monitoring and alphabet–arithmetic tasks. The amount of improvement in the response speed measure across the younger and older adults in the single-task versions of the alphabet–arithmetic and monitoring tasks was 7.0 and 6.9%, respectively. The comparable improvement scores for the dual task versions of the alphabet–arithmetic and monitoring tasks were 18.4 and 16.0%, respectively. This twofold improvement in dual task compared with single task performance with VP training seems to suggest, contrary to the complexity model, that dual tasks represent something more than complex versions of single tasks. The disproportionate improvement in dual tasks compared with single tasks during training in conjunction with the dual task specific transfer benefits observed with the scheduling and paired-associates tasks suggests that participants were acquiring task-coordination and management skills in addition to improving their performance on the single tasks as a result of VP training.

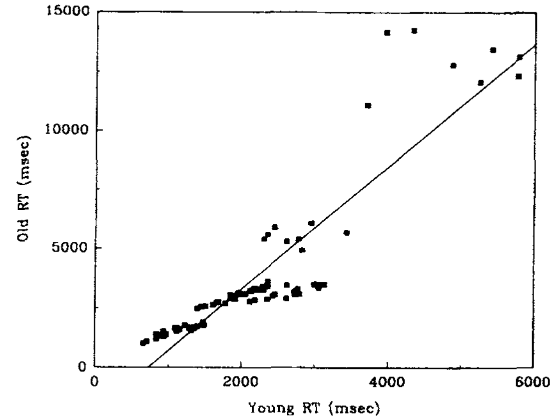

Figure 8. Reaction times (RTs) for older and younger participants for each of the experimental conditions in the monitoring, alphabet–arithmetic, scheduling, and paired-associates running memory tasks. Each of the points represents a cross-plot of younger adults' and older adults' mean RTs for a specific condition. Solid line represents the *a* fit of the following function: old RT = i + (young RT $*$ s), where i = intercept and s = slope.

A second aspect of our data is also inconsistent with the predictions of the complexity (McDowd & Craik, 1988) and general slowing models (Cerella, 1985, 1990; Salthouse, 1985). Evidence in favor of the complexity and general slowing models has often been provided by showing that older adults' response speed can be represented as a monotonic function of young adults' response speed. This function has often taken the form of old RT = i + (s $*$ young RT), where i (intercept) = 0 and s (slope) = 1.5. In an effort to examine our data within this context, we fit a linear function of the form just described to all of the pretraining, training, and transfer conditions in our four experimental tasks. Figure 8 presents a Brinley (1965) plot of 80 data points that represent each of the experimental conditions in the four tasks. As indicated in Table 4, the slope and intercept for the linear fit of the complete data set was 2.5 and −1,775 ms, respectively (R^2 = .81). If we assume, as is the case for the complexity model, that the age-related RT difference should increase as a function of task complexity regardless of whether the tasks are performed in a single- or dual task context, then we would expect similar slopes and intercepts even when the single- and dual task data are fit separately. Table 4 shows that this is not the case. However, it is important to determine whether the different slopes and intercepts that have been obtained in the single- and dual task fits are meaningfully different than those obtained when the entire data set was fit with the linear equation. This question was addressed by refitting the single and dual task data with the slope fixed at 2.5 and the intercept fixed at −1,775 (e.g., the slope and intercept obtained from the fit of the combined single- and dual task data). As shown in the table, the r^2 for the constrained dual task fit is only .04 less than that of the unconstrained dual task fit. However, the multiple correlation squared for the single-task constrained fit is .22 less than that for the unconstrained single task fit. Thus, these data

Table 4
Linear Regressions of Younger Adults' Reaction Times on Older Adults' Reaction Times

Data in fit	Slope	Intercept	r^2
All	2.5	−1,775	.81
Dual task	2.8	−2,309	.85
Single task data	1.7	−328	.71
Constrained dual task	2.5	−1,775	.81
Constrained single task	2.5	−1,775	.49
Arithmetic task	2.5	−141	.72
Monitoring task	0.6	1,568	.54
Scheduling task	0.8	582	.85
Paired-associates task	1.1	972	.94

Note. Old RT = i + (Young RT $*$ s), where i = intercept, s = slope, and RT = reaction time. The constrained fits are performed with the slope (2.5) and intercept (−1,775) obtained from the fits with the complete data set.

suggest that, contrary to the predictions of the complexity model, single- and dual task RTs of younger and older adults are not well fit by a single linear function.[3]

Another theoretical framework that we believe provides a reasonable account of our training data while also being compatible with the neurophysiological and anatomical data suggests that normal aging is associated with decreases in the ability to manage and coordinate multiple processes, skills, and tasks. This task coordination and management hypothesis, although not yet well articulated (but see Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Madden, 1986; Salthouse et al., 1984), is consistent with substantial data that suggest that older adults have more difficulty than younger adults in switching rapidly between two tasks (Hawkins et al., 1992), preparing for one task while performing another task (Jennings et al., 1990), coordinating patterns of movements between their hands (Stelmach et al., 1988), and performing one task while monitoring for a stimulus that indicates that an overt response should be aborted (Kramer et al., 1994). In each of these situations, successful performance depends on the coordination of multiple processes and task components.

Interestingly, a number of studies have suggested that the frontal regions of the brain, those regions most affected by the process of normal aging, are also implicated in task coordination and management functions. For example, Duncan (in press) reported that patients with lesions in the frontal lobes have great difficulty performing dual tasks. Corbetta, Miezin, Dobmeyer, Shulman, and Peterson (1991) found substantial activation of the anterior cingulate, a component of the frontal lobes, as participants performed dual tasks in a positron emission tomography (PET) study. Finally, Shallice and Burgess (1991) reported an association between the ability to shift cognitive and response sets and frontal lobe function.

These data are particularly interesting when considered with respect to the relatively specific and regional changes in brain function that accompany normal aging. For example, studies examining the loss of neural tissue during aging suggest that such changes are most prominent in the frontal lobes and the regions to which they connect: the basal ganglia and the thalamus (Haug et al., 1983; Scheibel & Scheibel, 1975). Additionally, reductions in cerebral blood flow occur earlier and are more pronounced in the frontal lobes than they are in other brain regions (Gur, Gur, Obrist, Skolnick, & Reivitch, 1987; Shaw et al., 1984; Warren, Butler, Katholi, & Halsey, 1985). Finally, a number of studies have found larger age-related decrements in tasks that are sensitive to frontal lobe function than tasks that are sensitive to the processing associated with other regions of the brain (Arbuckle & Gold, 1993; Loranger & Misiak, 1960; Whelihan & Lesher, 1985).

In summary, we have argued that our data, as well as other data collected in dual task paradigms, are more consistent with the hypothesis that age-related dual task performance decrements are the result of the decreased efficiency of a specific function or functions that subserve the coordination of multiple processes, tasks, and skills rather than a general deficit in information processing. This proposal receives support from neurophysiological and anatomical studies that suggest specific rather than general changes in brain function during aging. Furthermore, studies reported that successful dual task performance is dependent, in part, on those regions of the brain, the frontal lobes, that are most susceptible to normal aging.

Attentional Control and Driving

One important issue that we have not yet addressed is the potential applicability of our findings to everyday activities of younger and older adults. In the United States, motor vehicle accidents are responsible for more than 50% of all deaths resulting from unintentional injuries among adults (National Safety Council, 1993). Of relevance to our program of research, a number of studies have

---

[3] The fits of the individual task data presented in the Table 4 also suggest that the nature of the task cannot be ignored when estimating age-related slowing. An inspection of these fits shows that young–old slopes range from 0.6 for the monitoring task to 2.5 for the alphabet–arithmetic task, suggesting that in some tasks there is no evidence for age-related slowing. However, it is important to note that the older adults were significantly less accurate in their performance in three of the four tasks (e.g., monitoring, alphabet–arithmetic, and paired-associates running memory). Unfortunately, there is as yet no agreed-on method for treating accuracy together with latency within the context of general slowing and complexity models (but see Strayer & Kramer, 1994, for a possible solution).

found an association between accident rates and measures of attentional control.

For example, Avolio and colleagues (1985) administered a battery of information-processing tests to 72 drivers between the ages of 28 and 59 years and found that the best predictor of automobile accident rates was the number of switching errors in auditory and visual selective attention tests (see also Kahneman, Ben-Ishai, & Lotan, 1973). In these tasks, participants were required to monitor one source of information for targets and ignore another source of information. After the presentation of a number of discrete stimuli, a signal was presented that instructed participants to monitor the other information source. A switching error occurred if participants failed to report the occurrence of stimuli in the newly relevant visual location (visual task) or ear (auditory task). Participants with a higher number of automobile accidents in the past 10 years had more difficulty rapidly reorienting their attention than those who had few automobile accidents.

Ball and Owsley (1991; see also Owsley et al., 1991) examined the utility of a measure of the useful field of view (UFOV) for predicting accident rates of elderly drivers. The UFOV includes a number of components that tap factors such as processing speed, resistance to distraction, and divided attention. Ball and Owsley found in several studies that performance on the UFOV task is predictive of automobile accident rates among older drivers. Interestingly, Ball, Beard, Roenker, Miller, and Griggs (1988) examined the effects of practice on performance in the UFOV test and in particular on the ability of participants to localize targets in the periphery as a function of the difficulty of a foveal target identification task. After 5 days of practice, young, middle-aged, and older adults were able to expand their UFOV by approximately 10 degrees. Furthermore, these practice effects were maintained over a 6-month period.

The research just reviewed suggests that reduced attentional control and, in particular, task switching and dual task performance are associated with increases in automobile accident rates. Unfortunately, at present, there is little evidence to suggest that the results obtained in laboratory-based attentional training programs will generalize to everyday tasks such as driving (but see Gopher, 1993). However, the retention data obtained by Ball and colleagues (1988), in conjunction with our finding of a generalization of VP training benefits to novel tasks, are sufficiently encouraging to justify continued examination of the efficacy of different training strategies for attentional control and the relation of training benefits to real world skills such as driving.

Some Final Caveats

Although our findings provide important new insights into the mechanisms that underlie learning and performance in dual task settings, there are also a number of important unanswered questions. First, although it is clear that the task coordination skills that are learned during VP training can be transferred to novel tasks, we have yet to determine the extent to which such skills can be retained over days, weeks, and months. Second, it is clear from the data obtained in the training sessions that participants trained with the VP strategy were still showing evidence of learning at the end of the training intervention. Thus, an important question for future research is whether the VP advantages could be enhanced with additional training.

Third, although the VP dual task training strategy that we used appears to offer several important advantages over the more traditional FP training strategy, there were also some costs associated with the VP strategy, especially for the older adults. The older adults in the VP group displayed substantially poorer performance than the older adults in the FP group during the first two sessions of training. These initial costs could be due to the requirement to monitor performance feedback constantly in the VP conditions, in essence the addition of an extra task that might have been particularly detrimental to the older participants. In fact, the initially slower acquisition in the same training condition that resulted in superior transfer performance (e.g., VP training) is consistent with a large body of literature in motor learning that suggests that factors maximizing transfer and retention of skills, such as random practice, reduced feedback, and variable practice, also tend to be associated with slower acquisition of skills (Schmidt & Bjork, 1992). Future research should explore whether these initial costs associated with

VP training for older adults can be reduced or eliminated by adaptively increasing the frequency with which study participants are required to switch processing priorities between tasks.

References

Ackerman, P., Schneider, W., & Wickens, C. (1984). Deciding the existence of a time sharing ability: A combined methodological and theoretical approach. *Human Factors, 26,* 71–82.

Anderson, J. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369–406.

Arbuckle, T., & Gold, D. (1993). Aging, inhibition and verbosity. *Journal of Gerontology: Psychological Sciences, 48,* 225–232.

Avolio, B., Kroeck, K., & Panek, P. (1985). Individual differences in information processing ability as a predictor of motor vehicle accidents. *Human Factors, 27,* 577–587.

Baddeley, A., & Hitch, G. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (pp. 47–90). New York: Academic Press.

Bahrick, H., Noble, M., & Fitts, P. (1954). Extra-task performance as a measure of learning a primary task. *Journal of Experimental Psychology, 48,* 298–302.

Bahrick, H., & Shelly, C. (1959). Time sharing as an index of automatization. *Journal of Experimental Psychology, 56,* 288–293.

Ball, K., Beard, B., Roenker, D., Miller, R., & Griggs, D. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America, 5,* 2210–2219.

Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors, 33,* 583–595.

Baron, A., & Mattila, W. (1989). Response slowing of older adults: Effects of time-limit contingencies on single and dual-task performance. *Psychology and Aging, 4,* 66–72.

Birren, J. (1965). Age changes in the speed of behavior: Its central nature and physiological correlates. In A. Welford & J. Birren (Eds.), *Behavior, aging and the nervous system* (pp. 191–216). Springfield, IL: Charles C Thomas.

Birren, J. (1974). Translations in gerontology—From lab to life: Psychophysiology and speed of response. *American Psychologist, 29,* 808–815.

Birren, J., Woods, A., & Williams, A. (1980). Behavioral slowing with age: Causes, organization and consequences. In L. Poon (Ed.), *Aging in the 1980s: Psychological issues* (pp. 293–308). Washington, DC: American Psychological Association.

Brickner, M., & Gopher, D. (1981). Improving time-sharing performance by enhancing voluntary control of processing resources (Report No. HEIS-81-3). Haifa, Israel: Technion-III, Faculty of Industrial Engineering and Management, Research Center for Work Safety and Human Engineering.

Brigham, M., & Pressley, M. (1988). Cognitive monitoring and strategy choice in younger and older adults. *Psychology and Aging, 3,* 249–257.

Brinley, J. F. (1965). Cognitive sets, speed and accuracy in the elderly. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging and the nervous system* (pp. 114–149). Springfield, IL: Charles C Thomas.

Brookings, J., & Damos, D. (1991). Individual differences in multiple task performance. In D. Damos (Ed.), *Multiple task performance* (pp. 363–385). London: Wiley.

Brown, T., & Carr, T. (1989). Automaticity in skill acquisition: Mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 686–700.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67–83.

Cerella, J. (1990). Aging and information processing rate. In J. Birren & K. W. Schaie (Eds.), *Handbook of psychology of aging.* (pp. 201–221). New York: Academic Press.

Corbetta, M., Miezin, F., Dobmeyer, S., Shulman, G., & Petersen, S. (1991). Selective and divided attention during visual discriminations of shape, color, and speed: Functional anatomy by positron emission tomography. *Journal of Neuroscience, 11,* 2383–2402.

Craik, F. I. M. (1977). Age differences in human memory. In J. Birren & K. Schaie (Eds.), *Handbook of the psychology of aging.* New York: Van Nostrand Reinhold.

Crosby, J., & Parkinson, S. (1979). A dual-task investigation of pilots' skill level. *Ergonomics, 22,* 1301–1313.

Crossley, M., & Hiscock, M. (1992). Age-related differences in concurrent task performance of normal adults: Evidence for a decline in processing resources. *Psychology and Aging, 7,* 499–506.

Damos, D. (1978). Residual attention as a predictor of pilot performance. *Human Factors, 20,* 435–440.

Damos, D. (1991). Dual-task methodology: Some common problems. In D. Damos (Ed.), *Multiple task performance* (pp. 101–119). London: Wiley.

Damos, D., & Wickens, C. (1980). The identification and transfer of timesharing skills. *Acta Psychologica, 46,* 15–39.

Duncan, J. (in press). Attention, intelligence and the frontal lobes. In M. S. Gazzangia (Ed.), *The cognitive neurosciences.* Cambridge, MA: MIT Press.

Fabiani, M., Buckley, J., Gratton, G., Coles, M., Donchin, E., & Logie, R. (1989). The training of complex task performance. *Acta Psychologica, 71,* 259–299.

Fisk, A., Lee, M., & Rogers, W. (1991). Recombination of automatic processing components: The effects of transfer, reversal and conflict situations. *Human Factors, 33,* 267–280.

Fisk, A., & Rogers, W. (1991a). Development of skilled performance: An age related perspective. In D. Damos (Ed.), *Multiple task performance* (pp. 415–443). London: Wiley.

Fisk, A., & Rogers, W. (1991b). Toward an understanding of age-related memory and visual search effects. *Journal of Experimental Psychology: General, 120,* 131–149.

Freidman, A., & Polson, M. (1981). The hemispheres as independent resource systems: Limited capacity processing and cerebral specialization. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 1030–1058.

Gopher, D. (1982). A selective attention test as a predictor of success in flight training. *Human Factors, 24,* 173–184.

Gopher, D. (1993). The skill of attention control: Acquisition and execution of attention strategies (pp. 299–322). In D. Meyer & S. Kornblum (Eds.), *Attention and performance XIV.* Hillsdale, NJ: Erlbaum.

Gopher, D., Weil, M., & Siegel, D. (1989). Practice under changing priorities: An approach to training of complex skills. *Acta Psychologica, 71,* 147–179.

Gur, R. C., Gur, R. E., Obrist, W., Skolnick, B., & Reivitch, M. (1987). Age and regional cerebral blood flow at rest and during cognitive activity. *Archives of General Psychiatry, 44,* 617–621.

Haug, H., Barmwater, U., Eggers, R., Fischer, D., Kuhl, S., & Sass, N. (1983). Anatomical changes in aging brain: Morphometric analysis of the human prosencephalon. In J. Cerbos-Navarro & H. Sarkander (Eds.), *Neuropharmacology* (Vol. 21, pp. 1–12). New York: Raven Press.

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychology and Aging, 7,* 643–653.

Hertzog, C., & Vernon, M. C. (1993). Age differences in mental rotation task performance: The influence of speed–accuracy tradeoffs. *Journal of Gerontology: Psychological Sciences, 48,* 150–156.

Hunt, E., & Lansman, M. (1982). Individual differences in attention. In R. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 207–254). Hillsdale, NJ: Erlbaum.

Ishihara Color Blindness Test. (1989). Tokyo: Kanehara & Company.

Jennings, R., Brock, K., & Nebes, R. (1990). Age and specific processing capacities: A cardiovascular analysis. *Journal of Psychophysiology, 4,* 51–64.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kahneman, D., Ben-Ishai, R., & Lotan, M. (1973). Relation of a test of attention to road accidents. *Journal of Applied Psychology, 38,* 113–115.

Kaufman, A. S. & Kaufman, N. L. (1990). Kaufman Brief Intelligence Test. Circle Pines, MN: American Guidance Service.

Korteling, J. (1991). Effects of skill integration and perceptual competition on age-related differences in dual-task performance. *Human Factors, 33,* 35–44.

Korteling, J. (1993). Effects of age and task similarity on dual-task performance. *Human Factors, 35,* 99–114.

Kramer, A. F., Humphrey, D., Larish, J., Logan, G., & Strayer, D. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 9,* 491–512.

Kramer, A. F., Strayer, D. L., & Buckley, J. (1990). Development and transfer of automatic processing. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 505–522.

Lintern, G., & Wickens, C. (1991). Issues for acquisition and transfer of timesharing and dual-task skills. In D. Damos (Ed.), *Multiple task performance* (pp. 123–138). London: Wiley.

Logan, G. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527.

Logan, G., & Stadler, M. (1991). Mechanisms of performance improvement in consistent-mapping memory search: Automaticity or strategy shift? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 478–496.

Loranger, A., & Misiak, H. (1960). The performance of aged females on five nonlanguage tests of intellectual functions. *Journal of Clinical Psychology, 16,* 189–191.

Lorsbach, T., & Simpson, G. (1988). Dual-task performance as a function of adult age and task complexity. *Psychology and Aging, 3,* 210–212.

Madden, D. (1986). Adult age differences in the attentional capacity demands of visual search. *Cognitive Development, 1,* 335–363.

Madden, D. (1987). Aging, attention and the use of meaning during visual search. *Cognitive Development, 2,* 201–216.

McDowd, J. (1986). The effects of age and extended practice on divided attention performance. *Journal of Gerontology, 41,* 764–769.

McDowd, J., & Craik, F. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 267–280.

McDowd, J., Vercruyssen, M., & Birren, J. (1991). Aging, divided attention, and dual-task performance. In D. Damos (Ed.), *Multiple task performance* (pp. 387–414). Bristol, PA: Taylor & Francis.

Mowbray, G., & Rhoades, M. (1959). On the reduction of choice reaction time with practice. *Quarterly Journal of Experimental Psychology, 2,* 16–23.

Murrell, K. (1970). The effect of extensive practice on age differences in reaction time. *Journal of Gerontology, 25,* 268–274.

Myerson, J., Hale, S., Wagstaff, D., Poon, L., & Smith, G. (1990). The information loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review, 97,* 475–487.

National Safety Council. (1993). *Accident facts, 1993 edition.* Itasca, IL: National Safety Council.

Nebes, R. (1978). Vocal versus manual response as a determinant of age differences in simple reaction time. *Journal of Gerontology, 33,* 884–889.

Nestor, P. G., Parasuraman, R., & Haxby, J. (1989). Attentional costs of mental operations in young and old adults. *Developmental Neuropsychology, 5,* 141–158.

Nissen, M., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19,* 1–32.

Noble, M., Trumbo, D., & Fowler, F. (1967). Further evidence on secondary task interference in tracking. *Journal of Experimental Psychology, 73,* 146–149.

North, R., & Gopher, D. (1976). Measures of attention as predictors of flight performance. *Human Factors, 18,* 1–14.

Owsley, C., Ball, K., Sloane, M., Roenker, D., & Bruni, J. (1991). Visual perception/cognitive correlates of vehicle accidents in older drivers. *Psychology and Aging, 6,* 403–415.

Park, D., Smith, A., Dudley, W., & Lafronza, V. (1989). Effects of age and a divided attention task presented during encoding and retrieval on memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1185–1191.

Parkinson, S., Lindholm, J., & Urell, T. (1980). Aging, dichotic memory, and digit span. *Journal of Gerontology, 35,* 87–95.

Ponds, W., Brouwer, W., & van Wolffelaar, P. (1988). Age differences in divided attention in a simulated driving task. *Journal of Gerontology, 6,* 151–156.

Rabbitt, P. M. A. (1979). How old and young subjects monitor and control responses for accuracy and speed. *British Journal of Psychology, 70,* 305–311.

Rogers, W., & Fisk, A. D. (1991). Age-related difference in the maintenance and modification of automatic processes: Arithmetic Stroop interference. *Human Factors, 33,* 45–56.

Salthouse, T. (1982). *Adult cognition: An experimental psychology of aging.* New York: Springer-Verlag.

Salthouse, T. (1985). Speed of behavior and its implications for cognition. In J. Birren & K. Schaie (Eds.) *Handbook of psychology of aging* (pp. 400–426). New York: Van Nostrand.

Salthouse, T. (1990). Influence of experience on age-differences in cognitive functioning. *Human Factors, 34,* 551–569.

Salthouse, T., Rogan, J., & Prill, K. (1984). Division of attention: Age differences on a visually presented memory task. *Memory & Cognition, 12,* 613–620.

Salthouse, T., & Somberg, B. (1982). Skilled performance: Effects of adult age and expensive or elementary processes. *Journal of Experimental Psychology: General, 111,* 176–207.

Scheibel, M., & Scheibel, A. (1975). Structural changes in the aging brain. In H. Brody, D. Harmon, & J. Ordy (Eds.), *Aging* (Vol. 1, pp. 11–37). New York: Raven Press.

Schmidt, R., & Bjork, R. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science, 3,* 207–217.

Schneider, W. (1985). Towards a model of attention and the development of automatic processing. In M. Posner & O. Marin (Eds.), *Attention and performance XI* (pp. 475–492). Hillsdale, NJ: Erlbaum.

Schneider, W., & Fisk, D. (1982). Concurrent automatic and controlled visual search: Can processing occur without resource cost? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 261–278.

Schneider, W., & Shiffrin, R. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review, 84,* 1–66.

Shallice, T., & Burgess, P. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain, 114,* 727–741.

Sharps, M., & Gollin, E. (1987). Speed and accuracy of mental rotation in young and elderly adults. *Journal of Gerontology, 42,* 342–344.

Shaw, T., Mortel, K., Meyer, J., Rogers, R., Hardenberg, J., & Cutaia, M. (1984). Cerebral blood flow changes in benign aging and cerebrovascular disease. *Neurology, 34,* 855–862.

Shiffrin, R., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84,* 127–190.

Somberg, B., & Salthouse, T. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 651–653.

Stelmach, G., Amrheim, P., & Goggin, N. (1988). Age differences in bimanual coordination. *Journal of Gerontology, 43,* 18–23.

Strayer, D. L., & Kramer, A. F. (1994). Aging and skill acquisition: Learning–performance distinctions. *Psychology and Aging, 9,* 589–605.

Strayer, D., Wickens, C., & Braune, R. (1987). Adult age differences in speed and capacity of information processing: 2. An electrophysiological approach. *Psychology and Aging, 2,* 99–110.

Warren, L., Butler, R., Katholi, C., & Halsey, J. (1985). Age differences in cerebral blood flow during rest and during mental activation measurements with and without monetary incentive. *Journal of Gerontology, 40,* 53–59.

Wechsler, D. (1981). Wechsler Adult Intelligence Scale—Revised. San Antonio, TX: Psychological Corp.

Welford, A. T. (1958). *Aging and human skill.* London: Oxford University Press.

Welford, A. (1977). Motor performance. In J. Birren & K. Schaie (Eds.), *Handbook of psychology of aging* (pp. 450–496). New York: Van Nostrand.

Whelihan, W., & Lesher, E. (1985). Neuropsychological changes in frontal functions with aging. *Developmental Neuropsychology, 1,* 371–380.

Wickens, C. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and performance* (pp. 239–257). Hillsdale, NJ: Erlbaum.

Wickens, C., Braune, R., & Stokes, A. (1987). Age differences in the speed and capacity of information processing: 1. A dual-task approach. *Psychology and Aging, 2,* 70–78.

Wightman, D., & Lintern, G. (1985). Part-task training for tracking and manual control. *Human Factors, 27,* 201–312.

Zbrodoff, J., & Logan, G. (1986). On the autonomy of mental processes: A case study of arthimetic. *Journal of Experimental Psychology: General, 115,* 118–130.

Received February 12, 1994
Revision received July 15, 1994
Accepted July 29, 1994 ■
