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Division of attention: Age differences on a visually presented memory task

TIMOTHY A. SALTHOUSE, JANICE DAVENPORT ROGAN, and KENNETH A. PRILL
University of Missouri, Columbia, Missouri

Young and old adults were compared in their efficiency of remembering concurrently presented series of letters and digits in three separate experiments. Instructions and payoffs to vary attentional emphasis across the two types of material in different conditions allowed the examination of attention-operating characteristics in the two age groups. Strategy-independent measures derived from these attention-operating characteristics revealed that older adults exhibited greater performance deficits than young adults when dividing their attention between the two tasks, even though dual-task difficulty was individually adjusted for each subject. It was concluded that either the total amount of attention available for distribution or the efficiency of its allocation decreased with age even though the ability to vary one's attention between concurrent tasks in response to instructions and payoffs remained intact.

Difficulties in dividing one's attention across two or more activities have been postulated to be responsible for many of the perceptual, cognitive, and motor deficiencies observed with increased age. For example, Wright (1981) asserted that "one of the most replicable findings about short-term memory changes with increasing age is that older adults' performance is affected more adversely by divided attention conditions than is that of younger adults" (p. 605). Burke and Light (1981) and Craik (1977) have drawn similar conclusions based on extensive reviews of the literature on memory and aging. Indeed, several studies (e.g., Caird, 1966; Inglis & Ankus, 1965; Inglis & Caird, 1963; Parkinson, Lindholm, & Urell, 1980) have reported that older adults generally exhibit greater performance impairments than young adults when required to divide their attention between two concurrent tasks in dichotic-listening situations.

However, we believe that at least three problems hamper the interpretation of these divided-attention studies: lack of control over the individual's relative emphasis on one task or the other, unknown resource requirements for each task, and uncontrolled age differences on each task when performed in isolation. With respect to the first problem, one cannot hope to quantify the dual-task decrement if the magnitude of the decrement varies with differential emphasis on the two tasks; for example, a small decrement might result with heavy emphasis on Task 1 and light emphasis on Task 2, but a large decrement might be obtained when the tasks receive equal emphasis. The second problem relates to the fact that Task 1 may require, say, 5% of the total attentional capacity to produce a unit increase in performance, whereas Task 2 may require only 1% of the capacity to achieve comparable performance improvement. Because performance generally varies across individuals on both concurrent tasks, only qualitative comparisons of the severity of divided-attention impairment have been possible in the earlier studies.

With respect to the third problem, the added complexity posed by the division of attention may have different effects depending upon the proficiency with which the subjects handle the tasks in single, focused-attention, conditions. If different individuals perform at varying levels in single-task conditions, it is likely that they differ in the proportion by which task difficulty is increased by the requirement of having to perform two tasks simultaneously. As a consequence, many divided-attention comparisons in the past may have been confounded with overall level of difficulty such that the poorer-performing individuals in the single tasks experienced a greater increment in overall difficulty in the divided-attention conditions than the better-performing individuals because they were already operating closer to their performance limits.

The first two of these problems seem resolvable with a modification of a procedure introduced by Kinchla (1980) and Sperling (1978; Sperling & Melchner, 1978). Their method is to obtain data across several dual-task conditions, with each condition involving different relative emphases on the two tasks. In this manner, an attention-operating characteristic (AOC) can be constructed in which performance on Task 1 is represented along the ordinate and performance on Task 2 is represented along the abscissa. A given point on the AOC signifies a particular combination of Task 1 emphasis and Task 2 emphasis, but the complete function indicates the overall, emphasis-independent, divided-attention effect. Moreover, because the axes of the AOC are scaled in units of performance on each task, one can directly compare

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the effects of performance change in Task 1 in units of Task 2, thereby solving the problem of unknown resource requirements.

Our modification to the AOC procedure is to use the area above the AOC as a measure of divided-attention costs (cf. Somberg & Salthouse, 1982). The reasoning is that perfect division of attention would be manifested in an AOC consisting of a single point corresponding to the intersection of the lines representing maximum performance on each task. This pattern would show that performance on each task is unaffected by demands for performance on the other. Such an AOC would encompass the entire area of the dual-task space, and therefore the divided-attention cost would be 0. Less-than-maximum performance on one or both tasks would result in AOCs below and to the left of the optimum point, and thus the area above the AOC can be interpreted as a reflection of the costs of divided attention.

The problem of uncontrolled age differences in single-task conditions of dichotic-listening experiments was discussed by Parkinson et al. (1980), who pointed out that many studies reported trends for older individuals to have smaller memory spans than their young counterparts. In a study of their own, Parkinson et al. found that dichotic-listening differences between their young and old age groups disappeared when subjects were matched on digit span and screened for hearing deficits. Thus, it may be that slight performance differences are enlarged when the number of mental operations required to perform the task is increased, as is certainly the case when two tasks are performed concurrently.

An even more impressive demonstration of the importance of controlling for single-task performance when making comparisons in dual-task situations was evident in a recent experiment by Somberg and Salthouse (1982). Here, the same pattern of attention allocation was found in young and old adults with two concurrent perceptual discrimination tasks after stimulus durations were adjusted to yield equivalent performance across age groups in the single-task conditions. These results are especially convincing because the equating technique avoided "select group" interpretations that might be applied to the Parkinson et al. (1980) result described above. Similarly, although the two groups were identical in their dual-task performance, they still exhibited typical age trends in the duration required for a fixed level of perceptual accuracy with each component task. The apparent implication is that age differences found in other studies may not be solely attributable to the unique requirements of having to divide one's attention between two concurrent activities.

It seemed desirable to extend the Somberg and Salthouse (1982) procedure to a more demanding memory task that might be expected to involve greater amounts of processing over a longer period of time than the perceptual discrimination task. The present experiments therefore employed a visual concurrent-memory task with two distinct sets of material, each constituting a "channel." One set of material consisted of letters and the other of digits to facilitate "channel" categorization, and the divided-attention task was to remember as many items as possible from the two channels when they were presented concurrently. Instead of presenting the stimuli one pair at a time, all the stimuli were presented simultaneously to facilitate resource allocation across channels; that is, there should have been more leeway for participants to distribute their attention than with paced sequential presentation. A limited presentation time (3 sec) was employed to minimize organizational factors that might have resulted in the transfer of information into long-term memory.

To some researchers, it might seem strange to use the term "divided attention" in the present context. Our argument for the present usage is as follows: Something is responsible for effective performance on both single and dual tasks; that something has clear limitations in that performance cannot be infinitely increased; and whatever it is can easily be allocated or divided across distinct tasks. These are all characteristics commonly attributed to the concept of attention, and the fact that the tasks had a duration of 3 sec means merely that there was ample time for the operation of all relevant processes. It is true that these characteristics also apply to structural concepts such as memory capacity or the number of slots available in some finite storage system, and the present research results might as easily be interpreted with a structural metaphor. However, because of our interest in the process of altering emphasis from one task to another, and in interpreting the resulting functions as reflections of differential allocation of a flexible capacity, we prefer a more dynamic conceptualization of resource limitations to account for the findings.

EXPERIMENT 1

Method

Subjects. Twenty-four college students (mean age = 18.9 years, range = 18 to 22 years) and 24 older adults (mean age = 69.5 years, range = 59 to 82 years) participated in a single session of approximately 1.5 h. There were 11 males and 13 females in each group. A common finding in the psychological literature on aging is that increased age is associated with poorer performance on speeded measures, but is either unrelated to or positively correlated with measures of verbal ability. The present sample of subjects were consistent with these trends in that the young subjects had higher scores on the speed-based Wechsler Adult Intelligence Scale (WAIS) digit symbol substitution test [65.2 vs. 42.3; $t(46) = 8.15$, $p < .0001$], but lower scores on the Nelson-Denny Form C Vocabulary Test [20.8 vs. 23.1; $t(46) = 2.03$, $p < .05$], the latter perhaps due in part to a greater average number of years of education in the older sample [16.4 vs. 13.4; $t(46) = 5.70$, $p < .0001$]. The current samples can therefore be considered representative of their respective populations, at least in terms of the above measures. Indeed, if anything, the older subjects were superior to the young subjects on the dimension of verbal ability.

Apparatus. Stimuli were presented on a computer-controlled visual display monitor positioned in front of the seated subject. A laboratory computer was used to generate randomly ordered series of letters (all consonants) and digits (0-9) and to record and analyze responses.

Procedure. The subjects were first given instructions about the general nature of the task, and memory span for both digits and letters was then assessed. A list of material consisted of a vertical column of randomly generated items with the constraint that the same item could not occur in consecutive positions. A trial consisted of presentation of the list for 3 sec, after which the subject attempted to orally reproduce the items in their proper (top-to-bottom) sequence. The responses were keyed into the computer by the experimenter, and a correct trial was defined as all items being reported in the correct sequence. The number of items started with three and was increased by one with two correct reproductions of the sequence until four of five trials were incorrect, at which time the span was identified as the previous sequence length. The maximum sequence length correctly reproduced in each of two separate trials therefore defined the span. Two blocks of letters and two blocks of digits were presented in a counterbalanced order, and the average of the two assessments served as the memory span for each type of material.

In the dual-task trials, both a series of digits and a series of letters were presented simultaneously for 3 sec, with subjects being required to respond, again orally, to both. The two sets of material were arranged in two columns horizontally separated by approximately 5° of visual angle, with the material to be reported first always on the left. The number of items presented in the dual-task conditions was 75% (truncated to the nearest integer) of the individual's span length for each type of material, that is, 75% span length of digits and 75% span length of letters, yielding a total of 150% of the average of the spans for the two sets of material. (The 150% value was chosen to ensure that the composite task requirements exceeded a subject's capacity, but was not so overwhelming that it made the task too frustrating.)

Five experimental conditions were distinguished by the emphasis (manipulated by payoffs of 0¢ to 4¢ per correct response) the subjects were to give to each of the two memory tasks: 0/4, 1/3, 2/2, 3/1, and 4/0. Responses were always required to both series, but in the 0/4 and 4/0 emphasis conditions, random guesses for the unattended series would have been sufficient.

There were two blocks of trials, with each block containing five subblocks of 10 trials for each emphasis condition. The order of emphasis conditions (0/4 to 4/0 vs. 4/0 to 0/4) was counterbalanced across subjects. One-half of the subjects reported digits first and letters second for the first block, and the reverse for the second block. The remaining subjects reported letters first and digits second in the first block, and the opposite in the second block.

Results

The young adults had slightly higher letter spans [5.88 vs. 5.52; $t(46)=1.69$] and digit spans [7.27 vs. 6.96; $t(46)=1.16$] than the older adults, but the difference was not significant with either type of material. The percentages of correct responses in the dual-task conditions were subjected to a 2 (age)×2 (material)×2 (order)×5 (emphasis) analysis of variance. Age was a between-groups variable, and all other variables were within groups. Two additional analyses were also conducted. In one, the criterion for scoring recall attempts was relaxed to count an item as correct whether or not it was in the proper serial position. This "free-recall" analysis yielded results nearly identical to those reported below, but with a slightly smaller order effect due to the second order's benefiting more from the relaxed criterion. In another analysis, the possibility of differences between the trial-block sequences (i.e., performance on the first trial block vs. performance on the second) was examined, but no main effects or interactions were found, so that data were collapsed across this variable.

All the main effects in the initial analysis were significant: age—older individuals performed at a lower overall level than young individuals [$F(1,46)=5.35$, $p < .05$]; material—letters were more difficult to recall than digits [$F(1,46)=12.65$, $p < .001$]; order—the second series reported gave the subjects more difficulty than the first series [$F(1,46)=274.50$, $p < .0001$]; and, finally, emphasis—the subjects were able to shift their attention from one task to the other [$F(4,184)=520.72$, $p < .0001$]. The age differences must be qualified, however, by the presence of a significant age × order interaction [$F(1,46)=5.12$, $p < .05$]. As illustrated in Figure 1, both age groups were worse at recalling the second series, but the decrease in performance was greater for the older individuals. It also can be seen by the parallel curves that both age groups were comparable in their abilities to shift attention from one task to the other; similarity in the trends for both age groups is also indicated by the lack of a significant age × emphasis interaction. Only two other interactions were significant: order × emphasis [$F(4,184)=159.26$, $p < .0001$], because of more extreme scores for the first series recalled at both low and high emphasis conditions, and material × emphasis [$F(4,184)=4.76$, $p < .005$], because low-emphasis scores tended to drop lower for letters than for digits.

Because the interaction between age and order was significant, a closer examination of the differences was made by separate analyses on each order. The slight difference in favor of young adults on the first set recalled was not significant, and no difference was found with respect to material on this set. The subjects did alter their attentional emphasis on the first-recalled material, however, because the emphasis main effect was significant [$F(4,184) = 621.68$, $p < .0001$].

Performance of young and old adults diverged significantly on the second series reported [$F(1,46)=6.90$, $p < .05$]. The material main effect was also significant in the

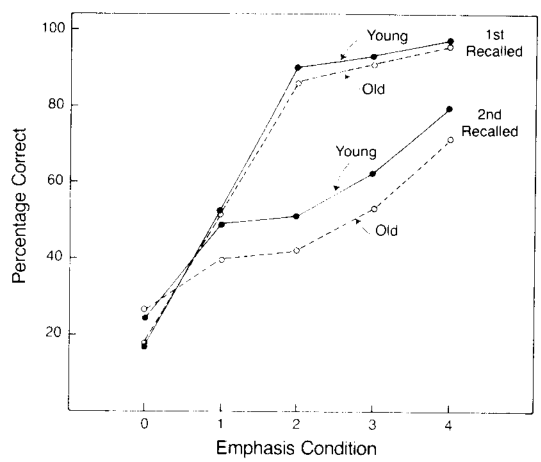

Figure 1. Percentage correct across emphasis conditions for tasks recalled first and tasks recalled second, collapsed across type of material, Experiment 1. A given point represents the average of 960 trials (20 observations for each of 24 subjects for both letter and digit material). The emphasis conditions are designated in terms of the payoff received for correct performance with that set of material.

second series [$F(1,46)=11.40$, $p < .005$], reflecting the fact that letters were more difficult than digits when they were reported second. The emphasis main effect continued to be significant in the second series [$F(4,184)=182.68$, $p < .0001$], as was an age × emphasis interaction resulting from the elderly group's lower performance on all but the lowest emphasis conditions in the material reported second [$F(4,184)=3.28$, $p < .05$].

It is interesting to note that performance was above chance (i.e., 10% for digits and 5% for letters) even in the 0-emphasis conditions. This appeared to be attributable to a tendency among many subjects to remember the first or the last item of the unattended (nonemphasized) set, in addition to as many items as possible from the attended set.

Divided-attention cost was first computed for each individual in a dual-task space with coordinates ranging from 0% to 100% on each task axis. The mean divided-attention cost regions, that is, the areas above the AOCs (see Figure 2), were .320 for young adults and .388 for older adults [$t(46)=2.46$, $p < .05$].

Relative divided-attention cost was also computed on the basis of each individual's functional performance region (Somberg & Salthouse, 1982). In this analysis, the dual-task space is restricted to the region defined by the minimum and maximum performance levels actually obtained on each task, rather than by theoretical limits of 0% and 100%, thus taking into consideration each individual's actual range of performance. Age-related decrements in performance comparable to those obtained with the absolute divided-attention cost measure were observed with these relative measures [$t(46)=2.68$, $p < .05$], with means of .270 for young and .355 for old.

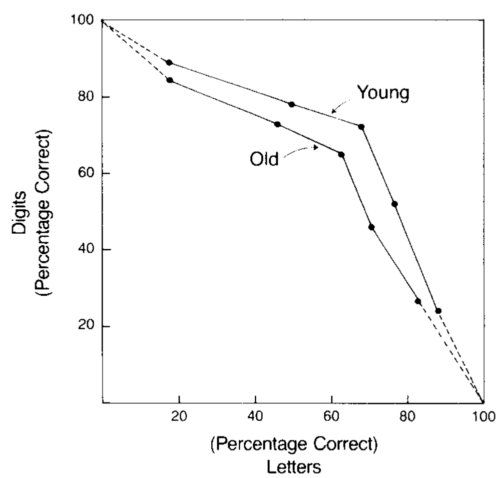

Figure 2. Empirically derived attention operating characteristics (AOCs) for young and old adults, Experiment 1. Each point represents performance in one emphasis condition (20 observations for each of 24 subjects). For example, the point in the upper left on both functions represents performance on the digit task (ordinate) and the letter task (abscissa) when subjects were instructed to place 100% emphasis on the digits and 0% emphasis on the letters.

Discussion

Older adults were found to perform less effectively than young adults across several different methods of measuring the divided-attention decrement. This finding may have to be qualified somewhat, however, because it was found that older adults performed nearly as well as young adults on the first set recalled, but the differences between groups became apparent on the second set recalled in the form of an age main effect and an age × emphasis interaction. Several dichotic-listening studies have reported a similar result (although always at a single, unknown, emphasis condition), and two common interpretations have been that older adults are more susceptible to either spontaneous decay of second-recalled items during the interval when first-set items are being recalled, or to response interference effects produced by the recall of first-set items (Craik, 1977). If either of these mechanisms were responsible for the present divided-attention results, it could be argued that structural, rather than capacity, limitations (Salthouse, 1982) were responsible for the present age differences. Experiments 2 and 3 were therefore designed to allow these interpretations to be directly investigated and to determine whether they could account for the present age differences in divided-attention ability.

EXPERIMENT 2

Experiment 2 was similar to Experiment 1, but only a single response was required to each set of material. One position in each array was cued at the time of the response, and the task was simply to identify the cued item. This manipulation greatly reduced the response requirements of the task, and, therefore, if response interference or spontaneous decay is the primary mechanism responsible for age differences in divided attention, the differences should have been minimized or eliminated.

Method

Subjects. Sixteen college students (mean age = 18.6 years, range = 18 to 22 years) and 16 older adults (mean age = 70.1 years, range = 60 to 84 years) participated in a single session of approximately 1.5 h. There were 5 males and 11 females in the young group and 4 males and 12 females in the old group. Mean years of education were 13.4 for the young and 17.1 for the old [$t(30)=5.29$, $p < .001$]. Mean scores on the WAIS digit symbol test were 67.1 for the young and 46.6 for the old [$t(30)=4.89$, $p < .001$]. In both measures, the current samples were similar to those of Experiment 1 and consistent with commonly reported trends. None of the subjects had participated in the previous experiment.

Procedure. The general procedure, apparatus, and most of the specific details were the same as those described for Experiment 1. There were three major differences. The first difference was that, in Experiment 2, each set of material in both single- and dual-task conditions involved a single response, consisting of the identity of the item cued by a set of question marks in the position occupied by the target in the stimulus array. The remaining items in the array were indicated with dashes, and below the array was the question "Which letter?" or "Which digit?" to remind the subject of the material he or she was to supply by pressing the appropriate key on the keyboard. The location of the probe in the stimulus array was varied randomly across sequence positions with the restriction that on the average each position would be probed equally often. A response was required for every probe even if only a guess. On a given block of dual-task trials, the order of digit and letter probes was constant, but this order was balanced across trial blocks for each subject.

The second procedural difference from the previous experiment was that the initial *single-task spans* were determined with a criterion of four correct responses out of five instead of only two out of five to minimize the contribution of chance with only a single response per trial. The third modification of the previous experiment was an increase from 10 to 20 trials per emphasis condition per block, for a total of 200 trials.

Results

The age differences were significant in the letter-span task [young=6.56, old=5.63; $t(30)=2.43$, $p < .05$], but not in the digit-span task [young=7.69, old=7.41; $t(30) < 1.0$]. The percentages of correct responses in the dual-task conditions were subjected to an age × material × order × emphasis analysis of variance. The following main effects were significant: age—young subjects had higher scores than older subjects [$F(1,30)=9.21$, $p < .005$]; order—the first series reported had higher scores [$F(1,30)=26.20$, $p < .0001$]; and emphasis—scores increased with attentional emphasis [$F(4,120)=460.90$, $p < .0001$]. The only significant interaction was between order and emphasis [$F(4,120)=2.92$, $p < .05$], indicating that the order effects were more pronounced at higher attentional emphases.

The significant trends are illustrated in Figure 3. Notice that, despite the significant order effect, performance on the second-reported material was much closer to that of the first-reported material than was the case in Experiment 1 (cf. Figure 1). This trend, together with roughly

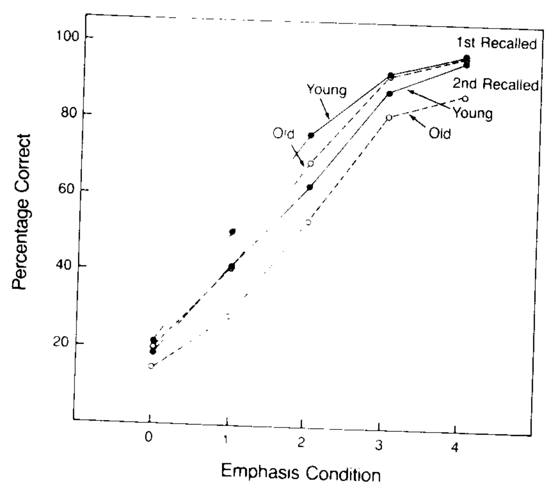

Figure 3. Percentage correct across emphasis conditions for tasks recalled first and tasks recalled second, collapsed across type of material, Experiment 2. A given point represents the average of 1,280 trials (40 observations for each of 16 subjects for both letter and digit material). The emphasis conditions are designated in terms of the payoff received for correct performance with that set of material.

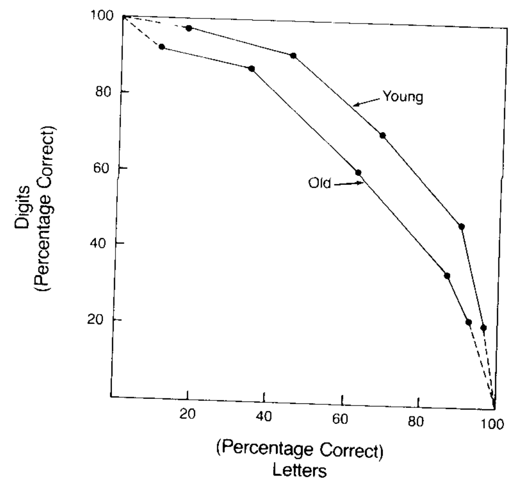

Figure 4. Empirically derived AOCs for young and old adults, Experiment 2. Each point represents performance in one emphasis condition (40 observations for each of 16 subjects).

similar age differences on both orders and the absence of a significant interaction between age and order, suggests that response interference effects are less pronounced than in Experiment 1.

The AOCs derived from these data are illustrated in Figure 4. As implied by Figure 4, older adults had a significantly higher absolute divided-attention cost than young adults [.339 vs. .240; $t(30)=3.16$, $p < .005$]. The age differences were in the expected direction but did not achieve statistical significance with the measure of relative divided-attention cost based on each individual's functional performance region [.382 vs. .320; $t(30) = 1.65$, $.15 > p > .10$].

Discussion

The major finding of Experiment 2 was that the age differences in divided-attention cost were still evident when the memory tasks are modified to minimize response interference. However, the age differences in the relative divided-attention cost measure were not significant, and the data in Figure 3 indicate that there was a tendency, albeit not statistically significant, for the age differences to be more pronounced on the second recalled material. It is therefore still possible to argue that some of the age differences in divided attention found in Experiment 1 were mediated by greater susceptibility to response interference or spontaneous decay with increased age. Experiment 3 was consequently designed to provide additional evidence relevant to this interpretation.

EXPERIMENT 3

In an attempt to completely eliminate response interference and decay effects for performance under divided-attention conditions, the memory-span tasks were further modified in two respects. One modification consisted of re-presenting all items in the array except the cued item at the time of response. It was believed that this would reduce the necessity of cycling through one's memory to locate the probe item at the time of recall, thereby minimizing the possibility of interference and shortening the time to generate a response. The second modification was to request a response from only one set of material in the dual-task conditions. That is, although both letter and digit arrays were always presented, on a given trial the subjects were queried about only one (randomly selected) array. Because only a single item was to be reported, there was no possibility of the recall of earlier items interfering with the recall of subsequent items, or of information to be reported second decaying during the reporting of information from the first series.

Method

Subjects. Sixteen college students (mean age = 19.1 years, range = 18 to 22 years) and 16 older adults (mean age = 66.6 years, range = 62 to 77 years) participated in a single session of approximately 1.5 h. There were 6 males and 10 females in the young group, and 4 males and 12 females in the older group. Mean years of education were 13.6 for the young and 15.1 for the old [$t(30) = 1.63$, $.15 > p > .10$]. Mean digit symbol scores were 66.3 for the young and 42.9 for the old [$t(30) = 6.33$, $p < .0001$]. These results, similar to those of Experiments 1 and 2, again suggest that the current samples were representative of their respective populations. None of the subjects had participated in either of the preceding experiments.

Procedure. Most of the procedural details were similar to those of the preceding two experiments. The major modifications were: adding the identities of the noncued items when prompting for the recall response; requesting a response from only one of a trial's two arrays in the dual-task conditions; and increasing the number of trials per block to 150, for a total of 300 across the two blocks, to partially compensate for the loss of data from the second-reported array. Determination of which array to probe on a specific dual-task trial was random, with the restriction that, on the average, the letter and digit arrays would receive an equal number of probes with each attentional emphasis.

Results

The age differences were not statistically significant with either the digit-span task [young = 8.16, old = 8.00; $t(30) < 1.0$] of the letter-span task [young = 6.81, old = 6.31; $t(30) = 1.23$, $p > .50$]. The only significant effect in the analysis of variance on the percentage correct responses in the dual-task conditions was emphasis [$F(4,120) = 268.20$, $p < .0001$]. The age effect in percentage correct in the dual-task conditions was in the expected direction (young = 70.1%, old = 67.3%), but failed to reach an acceptable level of statistical significance [$F(1,30) = 1.20$, $p > .25$].

Despite the similar overall level of performance in the two age groups, the AOCs still revealed an age deficit in divided-attention costs. The data are illustrated in Figure 5, in which it can be seen that older adults had higher divided-attention costs than young adults [.218 vs. .142; $t(30) = 2.20$, $p < .05$]. The age differences were also significant with the relative cost measure based on individually determined functional performance regions [.331 vs. .199; $t(30) = 2.61$, $p < .05$].

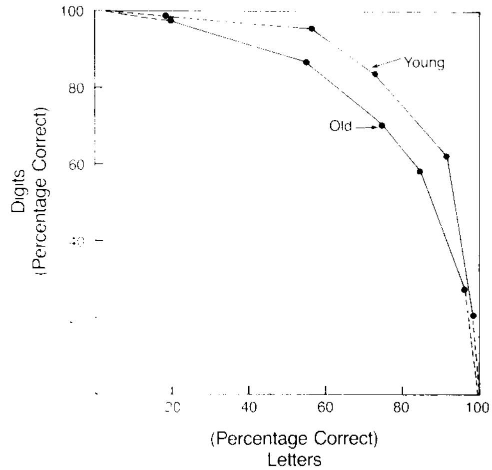

Figure 5. Empirically derived AOCs for young and old adults, Experiment 3. Each point represents performance in one emphasis condition (30 observations for each of 16 subjects).

Discussion

The major finding of Experiment 3 was that the age differences in divided-attention cost were replicated in a task with virtually no opportunity for response interference because only a single response was required on each trial. Moreover, in the present experiment, the age differences were significant in both the absolute and relative measures of divided-attention cost, despite lower statistical power than that in Experiment 1, due to a smaller number of subjects per age group. It can therefore be concluded that the age differences in divided-attention ability with two concurrent memory tasks are not attributable simply to greater output interference on the part of older adults.

GENERAL DISCUSSION

A primary focus of the present experiments was the use of the AOC analysis, as first used by Somberg and Salthouse (1982) with respect to divided attention and aging, in relatively demanding concurrent-memory-span tasks. Both the relative (Experiments 1 and 3) and absolute (Experiments 1-3) measures of divided attention cost indicated that older adults were more penalized than young adults by the divided-attention requirement, even after the difficulty of the concurrent tasks was adjusted to the same proportional level for each individual subject.

Obtaining roughly equivalent age differences in divided-attention costs across the three experiments not only demonstrates the reliability of the basic phenomenon, but also suggests that the locus of the age difference is in the initial stage of registration or encoding of the information. This inference is based on the nearly identical age trends when the potential for storage decay or response interference was systematically reduced from Experiments 1 to 2 to 3. Furthermore, the use of measures derived from AOCs, which represent dual-task performance across a range of emphases on the two tasks, indicates that the age differences are not attributable to differential biases or strategies favoring one task over the other.

It therefore seems reasonable to conclude that the age differences in the dual-task conditions are caused by age-related limitations in successfully encoding items when two simultaneous sets of material are presented. A relatively uninteresting interpretation of this finding might be that it is caused by slower shifts of fixation from one task (e.g., digits) to the other (e.g., letters) in older adults than in young adults. Although we cannot unequivocally reject this possibility, it is highly unlikely that it could account for more than a small proportion of the age differences because eye movements of 5° (the spatial separation between the arrays) typically require less than 45 msec in young adults (Salthouse & Ellis, 1980), and probably not much more in older adults. At these rates, a large number of redistributions of fixation could occur within a very small fraction of the 3-sec exposure time.

Our interpretation of the age differences in the dual-task conditions is that they are caused by an age-related reduction in a dynamic rather than a structural form of attentional capacity. This type of capacity may simply be equivalent to the rate of performing mental operations (Salthouse, 1982), or it may be analogous to what Craik and Byrd (1982) termed "mental energy." In either case, however, the fact that fewer total items were reported in the dual-task conditions than the average of the spans in the single tasks (see Table 1, as well as similar results by Inglis & Ankus, 1965, and Inglis & Caird, 1963, with dichotic listening tasks) suggests that performance was not limited by purely structural factors (e.g., number of slots). Instead, performance appears to be restricted by more active processes, such as the initial allocation, or subsequent redistribution, coordination, and monitoring, of capacity-demanding encoding operations across the two concurrent tasks. Either the amount of the resources available for these activities or the efficiency with which they are allocated to the various processing components appears to decrease with increasing age.

Despite less efficient divided-attention performance in older adults than in young adults, the two age groups seemed to allocate attention across conditions in a similar fashion, as indicated by the comparable trend of emphasis variations in all figures. This finding is important in that it suggests that the ability to distribute one's attention across two concurrent activities is relatively unaffected by increased age. There may be less attentional capacity available for distribution, or more overhead may be required to monitor the distribution of attention, but the effectiveness of actual attention allocation among concurrent activities does not seem to be reduced between 20 and 70 years of age. In this respect, then, characterizing the difficulty simply as poorer division of attention may be misleading because young and old adults appear to be equally proficient in the actual partitioning of the available attention across tasks in response to the varying emphasis conditions.

Table 1
Comparison of Average Single- and Dual-Task Performance

	Average Span In Single Task Conditions	Average Number of Items Recalled in Dual-Task Conditions
	Experiment 1	
Young	[illegible]	5.81
Old	6.24	5.25
	Experiment 2	
Young	7.13	6.30
Old	6.52	5.24
	Experiment 3	
Young	7.49	7.13
Old	7.16	6.47

Finding older adults to be more disadvantaged than young adults when required to divide their attention is inconsistent with Somberg and Salthouse's (1982) finding of no divided-attention differences across age groups comparable to those employed here. The apparent contradiction in the pattern of results may be attributable to differences in the complexity of the tasks employed in the two studies. The Somberg and Salthouse experiment used two perceptual discrimination tasks that seem to have involved minimal processing of information, when processing of information is defined as the hypothesized number of mental operations performed. The discrimination task required subjects merely to detect and respond to the presence of a target. When two discrimination tasks were performed concurrently, the number of mental operations increased, but the greater demands were still apparently within the capability of both age groups. The current experiments used memory-span tasks in which the individual was required to identify, remember, and then reproduce either all, or a specified member, of a series of letters and digits. Perhaps because of this added complexity, age differences were evident in the costs of dividing attention between two concurrent activities. In other words, the explanation that may account for the apparent discrepancy between the current findings and those of Somberg and Salthouse is simply that the larger the number of mental operations to be performed, the larger is the absolute age difference between young and older adults. Wright (1981) came to a similar conclusion when older adults performed worse than young adults on a complex single task, and analogous interpretations have been presented previously by Salthouse (1982, in press).

To summarize, older adults are penalized more than young adults by the requirement of dividing their attention between two concurrent tasks even when the difficulty of the dual-task situation is the same fixed percentage of single-task performance for each individual. However, because an earlier experiment with a simpler set of tasks revealed no age differences in divided-attention ability, and because the present AOC analyses revealed similar capabilities of dividing the available attentional resources, we suspect that the age-associated problem is not due simply to allocation of attention to alternative "channels" but, rather, is a problem in dealing with increased complexity of the total situation. Age differences may be present whenever composite task difficulty or demands upon processing capacity are great, and although divided-attention tasks often involve high levels of difficulty, they do not necessarily do so, and there are many single-task situations in which the level of task difficulty is high. Future research systematically analyzing the effects of additional mental operations (task difficulty) on the single-task and divided-attention performance of adults of varying ages would be desirable.

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