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Divided Attention Abilities in Young and Old Adults

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The literature on divided attention and adult aging has not taken age differences in single-task performance into account, and it has not been able to measure divided attention independently of resource allocation strategies. Two experiments are reported that controlled for these factors. In the first experiment, young (18–23 years) and old (57–76 years) subjects made responses to two simultaneous visual displays. Stimulus durations were manipulated to equate single-task performances, and across different conditions subjects were induced to vary the way in which they allocated resources between the two displays. In the second experiment, response time was the dependent variable; dual-task scores were assessed relative to each subject's single-task scores. No significant age difference in divided attention ability independent of single-task performance level was found in either experiment. The existing literature must be reexamined in light of these issues.

Whether older adults are less capable of dividing their attention among two or more simultaneous tasks than their younger counterparts seems to be a question that would inspire little controversy. Craik (1977) summarized the prevalent position on this issue:

> 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, either between two input sources, input and holding, or holding and responding. (p. 391)

Although the majority of the researchers who have investigated this problem have concluded that there is a significant age effect on performance of divided attention tasks, many of their findings may have alternative interpretations. A closer inspection of the available literature suggests that it is beset with problems numerous enough to prohibit definitive conclusions.

The first difficulty in this research lies in the restricted number of experimental paradigms that have been used to investigate divided attention effects. Dichotic listening tasks comprise a rather substantial segment of the research intended to discover whether an age effect exists on divided attention tasks. In the dichotic listening procedure, subjects are presented with two simultaneous auditory messages—one to each ear. The stimuli typically consist of strings of digits or monosyllabic words. The task of the subject is to reproduce the two messages. Most researchers report that there is an overall age-related impairment on this task. However, despite the frequency with which the paradigm has been studied, there does not exist a consensus about what processes are responsible for this effect.

The initial research in this area, from the laboratories of Inglis and his colleagues (Inglis & Ankus, 1965; Inglis & Caird, 1963; Mackay & Inglis, 1963), suggested that the locus of the age effect was a short-term memory deficiency of older adults. Using Broadbent's (1958) model of information processing, they argued that if it was necessary to hold the message from one ear in a storage system while the message from the other ear was being output, a memory deficit would show up in impaired performance on the second ear reported. Inglis's work confirmed this hypothesis by showing that the performance of older adults was worse than that of young adults on the second channel reported, but essentially equivalent on the first channel reported.

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Craik (1965) reasoned that if no instructions were given to the subjects regarding which channel to reproduce first, as was the case in the studies by Inglis and Caird (1963) and Mackay and Inglis (1963), it is likely that subjects would commence with the channel that was easier for them to recall. The superiority of a given channel may be the cause rather than the effect of its prior reproduction. Craik found that when the recall order was specified to the subjects there was an age decline on both channels, although generally there was a larger decrement on the second channel.

Clark and Knowles (1973) argued that the age deficit in dichotic listening is due to a perceptual impairment. They suggested that the critical comparison is not performance on the first channel versus performance on the second, but how well subjects can reproduce the message in the left ear in relation to their ability to reproduce the message in the right ear. The right ear is typically the dominant one, and stimuli presented to it tend to be more accurately perceived. Any perceptual impairments would be magnified in the nondominant ear regardless of whether its message was reported first or second. Clark and Knowles systematically varied whether the right or left ear was to be the first channel reported. They found that performance was generally lower on the second channel, but this was equally true of both young and old adults. Performance was also lower in the left ear than in the right ear, and this difference did increase as a function of the age of the subjects. These data are supportive of the hypothesis that perceptual processes may be responsible for the age effect in dichotic listening tasks. Other studies, however (e.g., Craik, 1965; Inglis & Ankus, 1965) also manipulated which ear should be reported first and did find significant Age × Order interactions.

It is unfortunate that in the examination of adult age differences in divided attention ability there has been such an overemphasis on a single methodology—particularly one in which there is so much ambiguity about the nature of the age effect. For a convincing argument to be made that older adults are less capable of dividing their attention than younger adults, a wider range of paradigms must be employed.

A second issue that makes the existing literature on aging and divided attention less than conclusive is that on a large variety of laboratory tasks, younger adults perform more capably than older adults. This is particulary true in tasks with a critical speed element, where sizeable age differences are almost invariably reported. Consequently, there may be a problem interpreting many divided attention results. In many dual-task studies where subjects are given two or more tasks to perform simultaneously, we would expect to find significant age effects under single-task control conditions. Given such initial discrepancies, how much of an age difference in performance should we expect under dual-task conditions?

This problem has several potential solutions, but at the present time no study has adequately resolved it. An experiment by Lipps Birch (1978) offered one approach to this issue. Her study examined age differences among children, but the theoretical issues are similar. Lipps Birch found that the older children were originally more competent on each of the measures under single-task conditions. She then gave practice to the younger children until their performance was comparable to that of the older children. When the subjects were put back into dual-task conditions, no age differences were found. This study seemingly argues against any age-related divided attention effects in children when differences in single-task performance are controlled for. It is likely, however, that the initial practice given to the younger subjects made the experimental tasks more automatic (i.e., less attention-demanding) for them than they were for the older subjects. As increased automaticity facilitates time-sharing, the practice trials may have given too much of an advantage to the younger children.

A second solution to this problem has been to match subjects on single-task performance. Although older adults may tend to be inferior to younger adults on some particular measure, it is frequently possible to find a selected sample of older subjects who can perform at the level of a sample of younger subjects. This was the approach taken in a dichotic listening study by Parkinson, Lindholm, and Urell (1980). They reasoned that if the age effect in dichotic listening performance is a short-term memory phenomenon, it should be possible to eliminate the age difference by matching subjects on a standard digit-span test. These investigators found that when they accomplished this, the age effect and the Age × Order (first ear vs. second ear) interaction were eliminated. However, the problem with these types of matching procedures is that they may select subjects who are atypical of their age group (i.e., superior older subjects or inferior young subjects) on those variables with which digit span covaries. That there is a correlation of about .66 between the Digit Span subscale of the Wechsler Adult Intelligence Scale (WAIS) and the full-scale WAIS IQ (Matarazzo, 1972) lends support to this line of reasoning.

It may also be possible to deal with the issue of age differences in single-task performance through the type of statistical analyses employed. Differences in baseline may often be controlled for by comparing each person's score under experimental conditions to their score under control conditions. Thus, rather than testing for an absolute age difference in divided attention effects, this procedure examines any age-related divided attention effect relative to each age group's performance under single-task conditions. Talland (1962) performed this type of analysis. Subjects in this experiment performed two manual tasks both separately and simultaneously. Talland found the same pattern of age decrements with absolute and relative measures. On the easier of the two tasks there was a substantially larger loss of speed due to divided attention demands for the older subjects than there was for the young, but virtually no age difference was found in the divided attention decrement on the more complicated tasks. Although in this study it did not matter whether relative or absolute scores were used, there are no other instances in which both types of analyses have been done, and it is possible that different patterns could be evident with the two measures. More data are required before it can be said whether absolute or relative analyses are most appropriate.

Perhaps the ideal solution to this problem is merely to find situations in which there is no age difference on single-task measures. This is quite difficult to accomplish, and when it is done the tasks usually turn out to be ones with a high degree of automaticity, they thus show no time-sharing effect in either age group. It may be possible to find tasks that have some dimension (e.g., stimulus duration) that may be manipulated to artificially equate the performance of subjects of different ages. This strategy is employed in the present article.

The third difficulty with the current literature on age effects in divided attention is closely tied to the baseline differences just discussed. A number of studies not only fail to address age differences in single-task measures but do not even collect data under single-task conditions. It was previously argued that even when these data are available, assessing divided attention performance may be difficult; without such data the task is impossible. For example, a study by Broadbent and Heron (1962) had young and old subjects perform a digit cancellation task that on some trials was combined with an auditory monitoring task. Because this experiment had trials in which the cancellation task was performed alone, it is possible to determine the effect on that task of having to perform a concurrent monitoring task. However, as the monitoring task was never performed alone it is impossible to determine what type of divided attention cost there was on that task. That the young subjects were better on the monitoring task under dual-task conditions than the older subjects may have been due to their ability to divide their attention between the cancellation and monitoring tasks. Alternatively, it may have been due to their superiority on monitoring tasks under any conditions.

Subjects in an experiment by Kirchner (1958) made key presses in response to a pattern of rapidly moving lights. In different conditions responses were required to the position of the current light ("no-back" condition), the position of the immediately preceding light ("one-back" condition), or the second ("two-back") or third ("three-back") preceding light. Viewing this as a dual-task situation, the subject simultaneously had to (a) respond to the appropriate light and (b) remember the previous sequence of lights. The "no-back" condition provided a measure for the responding task without simultaneously having to remember light sequences, but there was no comparable condition for the memory component. It is unclear whether the impaired performance of the older subjects under "one-back," "two-back," and "three-back" conditions is a consequence of poor divided attention ability or merely inability to recall proper light sequences.

A final issue that has not been adequately dealt with in the available literature is that it is necessary to measure divided attention independently of resource allocation strategies. The finding that older adults perform at a level below that of younger adults on one of several concurrent tasks may be evidence that the older adults are less able to divide their attention among the various tasks. An alternative interpretation is that performance was lower on one task because the older subjects allocated a smaller proportion of their limited attentional resources to that task than did the young subjects. To decide which of these explanations is correct, it is necessary to examine the way in which a subject's performance on one task varies as a function of the subject's performance on concurrent tasks.

Norman and Bobrow (1975) have introduced Performance Operating Characteristics (POC) as a vehicle for this type of analysis. In a dual-task situation, performance on Task X may be plotted as a function of performance on Task Y. As more resources are allocated to one task, fewer are available for the other. Thus there tends to be a negative correlation between performance levels on the two tasks.

Sperling (1978; Sperling & Melchner, 1978) and Kinchla (1980) have derived empirical POCs by inducing subjects to vary the relative emphasis given to each of two simultaneous tasks. These functions provide a useful way of evaluating divided attention performance, because as the subject changes resource allocation strategies it is possible to measure loss in performance on one task relative to the corresponding gain in performance on the other. Whereas the comparison of single data points does not allow divided attention effects to be separated from resource allocation strategies, if the entire POC functions are analyzed, the two factors are separable. Changes in resource allocation strategies may be viewed as different points on the same POC; differences in divided attention ability are reflected by the existence of separate POCs. Similar arguments have been developed for the use of Receiver Operating Characteristics as a method of separating sensitivity from response bias in Signal Detection Theory (Green & Swets, 1966). Another goal of the present research was to apply this type of analysis to the investigation of adult age differences in divided attention performance.

To summarize, the following factors have reduced the conclusiveness of the available research on aging and divided attention: (a) overemphasis on a single experimental paradigm; (b) failure to account for age differences in single-task performance; (c) failure to report single-task measures on all tasks; (d) failure to measure divided attention independent of resource allocation strategies. This study is intended to specifically address each of these issues. If age differences in divided attention ability are found when the above factors have been considered, the position expressed by Craik (1977) will have received substantial support. Failure to find an age effect will suggest that Craik's assertion was perhaps too strong and that further investigation on this issue is needed.

A secondary goal of the current work is to establish methodological procedures that may be useful not only in the investigation of adult age differences but also for a range of between-subject comparisons.

Experiment 1

The purpose of Experiment 1 was to investigate adult age differences in divided attention performance in a situation that controlled the problems discussed above. The tasks involved the simultaneous tachistoscopic presentation of two independent visual displays. The subjects were required to indicate the presence or absence of a specified target on each display.

Although it has been found that there is a significant age difference in the ability to identify tachistoscopically presented stimuli (e.g., Eriksen, Hamlin, & Breitmeyer, 1970; Walsh, Till, & Williams, 1978; Walsh, Williams, & Hertzog, 1979), it is also true that performance on this type of task is directly related to exposure duration. Consequently, the performance of different age groups may be equated by allowing the older subjects a longer stimulus presentation than the younger subjects. Specifically, exposure durations were determined individually for each subject such that they would be 80%–90% accurate under single-task conditions. Subsequent age differences under dual-task conditions therefore could not be attributed to differences in initial performance level.

Another feature of the present study is that it involved the construction of entire POCs for each subject. Subjects were instructed, under different conditions, to vary the emphasis given to each of the two tasks. Divided attention ability could then be examined independent of allocation strategies.

Method

Subjects. Sixteen young adults (mean age, 19.8; range, 18–23) and 16 older adults (mean age, 65.1; range, 57–76) each participated in a single 90-min. session. The young subjects were Introductory Psychology students at the University of Missouri—Columbia who participated for extra course credit but were also paid bonuses of up to $5. The elderly subjects were members of the Columbia community. They were paid $7 for their travel and participation, and they also could earn up to $5 in bonuses. None of the subjects were residents of nursing homes or other care facilities. There were 5 males and 11 females in each age group. All subjects reported that they were in good health.

Some psychometric data were collected for each subject at the conclusion of the experimental session. Mean raw scores on the Digit Symbol subtest of the WAIS were 67.2 and 44.0 for the young and old subjects, respectively, $t(30) = 6.69$, $p < .001$. On the final 20 items of the Vocabulary subtest of the WAIS, the young adults had a mean score of 21.6, whereas the mean score for the older adults was 32.3 (maximum score = 40), $t(30) = 3.53$, $p < .01$.

Apparatus. The subjects sat in a darkened room, illuminated only by a small, shaded lamp. Stimuli were presented on a Tektronix 606 (P-31 phosphor) monitor in front of them. They responded by pressing buttons on two 10-key pushbutton telephone pads mounted next to each other on a board. A PDP-11/03 laboratory computer was used to generate stimuli and to record and analyze subjects' responses.

Procedure. Each trial consisted of the simultaneous presentation of two visual arrays. For each array the subject had to indicate the presence or absence of a specified target. The computer randomly determined whether or not a target was to appear on each display. This was determined independently for each array; target presence and absence were equally likely events.

One array contained four (.4° × .4°) Xs located at the corners of an imaginary (1.7° × 2.4°) rectangle on the screen. The target was a small (.2°) line extending from the vertex of one of the four Xs. The target could appear on any one of the four Xs and could point in any of four directions (up, down, left, right). On a trial in which the target was to be present it was randomly determined, with equal probabilities, in which of the 16 possible locations it would appear. The other array contained four (.3° × .3°) plus signs (+) located at the corners of an imaginary (1.1° × 1.4°) rectangle on the screen. The target in this array was also a small (.1°) line extending from the vertex of one of the four pluses. The target could appear on any of the four pluses and could point in any of four directions (northeast, southeast, southwest, northwest). It was equally likely that a target would appear in each of the 16 possible locations on this array. The two displays were concentric and were centered on the screen. As the pluses were located more foveally than the Xs, they were made smaller in an attempt to equate the difficulty of locating the targets on the two displays. Pilot data indicated that this was successfully accomplished.

The subjects used the left-hand keyboard to indicate their responses to the plus array. On each trial they pressed the 9 key on the keyboard if they thought that they saw a target and the 7 key if they did not. The right-hand keyboard was used to indicate their responses to the X array. The 9 key indicated the presence of a target, and the 7 key indicated that the target was absent. A forced-choice procedure was used in this task to minimize any response bias effects.

The subjects were first given general instructions about the nature of the task, and the displays were demonstrated to them. This was followed by a block of 50 practice trials in which the arrays were simultaneously presented for one second, and the subjects had to indicate the presence or absence of a target on each display.

A tracking procedure was then employed to determine for each subject what stimulus duration would result in an accuracy of 80%–90% when full attention was given to one of the two displays. For these trials the subjects had to respond to one of the displays, and the stimulus duration varied until the appropriate value was determined. For the first block of this procedure, half of the subjects in each age group responded only to the Xs. The remaining subjects began by responding only to the plus array. The initial stimulus duration for each subject was 800 msec. For the following 40 trials each time that the subject was correct the stimulus duration was decreased by 10 msec for the next trial. Each time the subject was incorrect the stimulus duration was increased by 10 msec for the next trial. Beginning with the 41st trial the subject's accuracy over the preceding 20 trials was calculated. If this accuracy was 80%–90%, the stimulus duration for the following trial remained the same as the previous one. If the accuracy for the last 20 trials was below 80%, the stimulus duration was increased by 10 msec for the next trial. If the calculated accuracy was greater than 90%, the stimulus duration was decreased by 10 msec. For each subsequent trial this procedure was repeated with each calculation based on the 20 immediately preceding trials. When 10 consecutive calculations resulted in accuracy of 80%–90%, the block ended. The average stimulus duration over the final 20 trials was used as the estimate for that block.

At the completion of this block, each subject performed a second tracking block with the alternate display from the one used for the first block. As in the first block, the initial stimulus duration was set at 800 msec, and the block continued until 10 consecutive calculations of the accuracy of the 20 preceding trials yielded a value of 80%–90%. At the conclusion of that block, a third block was run using the final duration estimate from the second block as the initial stimulus duration. The final block was run using the display type and duration estimate from the first block. This procedure assured that the final duration estimates were relatively insensitive to the value chosen for the initial exposure durations (i.e., 800 msec).

At the conclusion of the four tracking blocks, the stimulus duration estimates derived from the final block of each stimulus type were averaged. The resulting value was used as the stimulus duration for the experimental trials for that subject.

In the experimental trials the subjects again were exposed to both the plus display and the X display, and they had to respond to both. There were five experimental conditions, differing in the amount of emphasis that should be given to each display. In order to facilitate their resource allocation, bonus money for correct responses was offered in proportion to the desired emphasis for each display. In one condition (0/100) the subjects were asked to devote their total attention to the Xs and none of their attention to the pluses, and in another condition (100/0) they were asked to attend only to the pluses and to ignore the Xs. In both these conditions they were paid 1¢ for each correct response for the attended display and nothing for the display not attended. Although all conditions required responses to both displays on every trial, in these two conditions the subjects could merely guess for the unattended stimuli. In intermediate conditions (70/30, 50/50, 30/70) the subjects were asked to divide their resources between the displays and were rewarded accordingly (e.g., in the 70/30 condition they were paid .7¢ for each correct plus and .3¢ for each correct X). There were 10 practice and 100 experimental trials in each block; thus, subjects could earn a maximum of $1 for each block. For half of the subjects in each group the order of the conditions was 100/0, 70/30, 50/50, 30/70, 0/100. The other half of each group received the conditions in the reverse order.

Results and Discussion

Duration threshold data. The results of the tracking procedure yielded stimulus durations of 428.1 msec for the young subjects and 644.4 msec for the older subjects. The

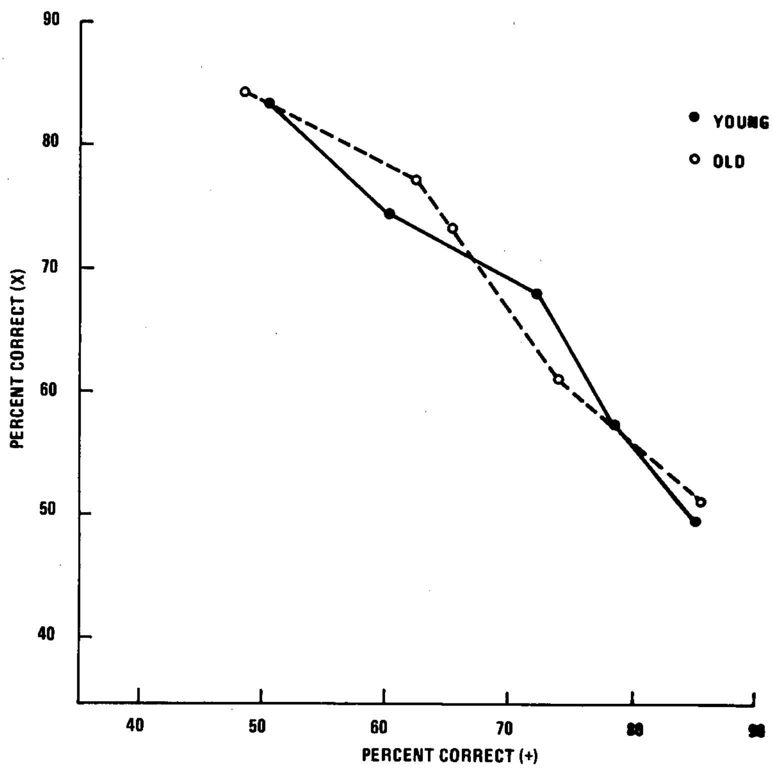

Figure 1. Accuracy of detecting targets in an array of Xs (ordinate) as a function of accuracy of detecting targets in an array of pluses (abcissa): Experiment 1.

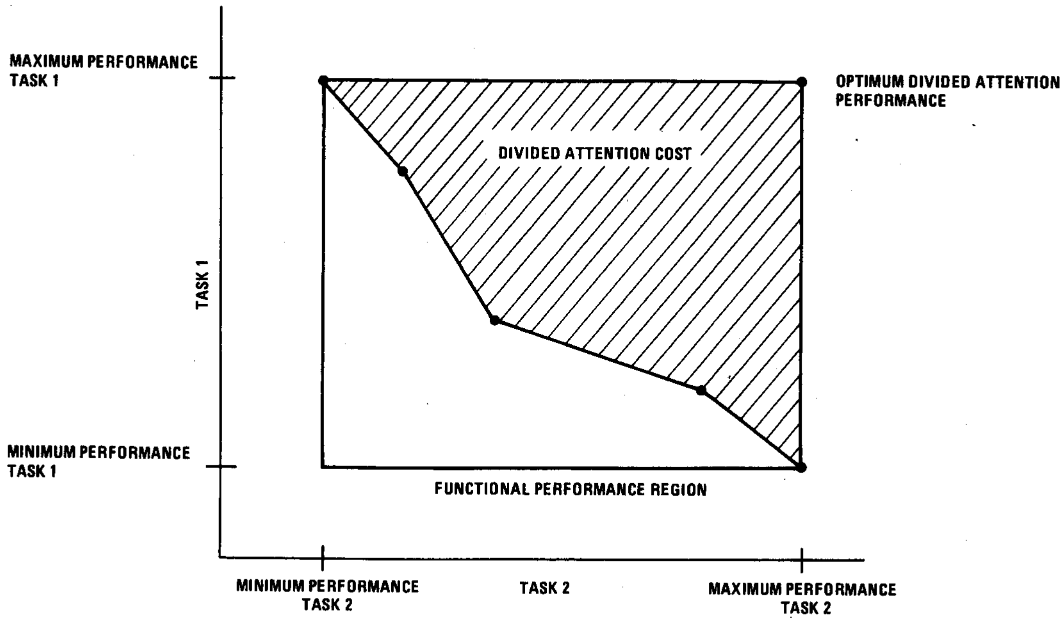

Figure 2. Sample performance operating characteristics. (Minimum and maximum performance occur when full attention is devoted to one display. Intermediate points represent conditions in which attention is divided between the two displays).

difference between these means was significant, $t(30) = 2.65$, $p < .05$.

Accuracy data. Each subject produced an accuracy percentage for both tasks under each of five experimental conditions. The means for the subjects in each group are illustrated in Figure 1. Inspection of this figure reveals nearly overlapping functions for the two age groups.

A separate analysis of variance (ANOVA) was performed on each task with two levels of age and five experimental conditions as factors. For each task there was a significant effect for condition: plus array, $F(4, 120) = 105.20$, $p < .01$; X array, $F(4, 120) = 109.57$, $p < .01$. For neither task was there a significant ($p < .05$) effect of age: plus array, $F(1, 30) = 1.18$; X array, $F(1, 30) = 2.72$, or for Condition × Age: plus array, $F(4, 120) = 1.79$; X array: $F(4, 120) < 1$. These results indicate that the performance of subjects did vary with the instructional emphasis requested of them, and that under all conditions the older subjects performed as well as the younger subjects. This traditional analysis indicates that with individual single-task performance controlled for, there was no age difference on dual-task performance.

It has been suggested (e.g., Duncan, 1980) that trials in which a target is present on two simultaneous displays are considerably more difficult than trials in which a target occurs on only one of the two displays. However Salthouse and Somberg (1982) used tasks which were similar to those in the present experiment and found that trial type (i.e., Signal, Array 1/Signal, Array 2; Signal, Array 1/No Signal, Array 2; No Signal, Array 1/Signal, Array 2; No Signal, Array 1/No Signal, Array 2) did not interact with either age or practice. Therefore, it was considered unnecessary to complicate the analyses in the present research by including this additional factor.

POC analysis. POC analyses were performed to examine divided attention performance independent of resource allocation strategies. As each subject had a score on each task under each of five conditions, POC functions for individual subjects similar to the group function in Figure 1 could be constructed.

Figure 2 illustrates the manner in which the analyses were conducted. In this example the five plotted points indicate the subject's performance in the five experimental conditions. The Functional Performance Region (FPR) is the rectangular area that is delineated by the maximum performance achieved by the subject on each task (i.e., performance under 100/0 and 0/100 conditions). It is that region that defines the potential performance levels of the subject. If the subject has a perfect ability to divide attention between the two tasks, performance on the three intermediary conditions (30/70, 50/50, 70/30) should lie on the point at the upper right corner of the FPR. To the extent that there is a cost for dividing one's attention, performance on those conditions will be below and to the left of that corner. Thus, the size of the region marked Divided Attention Cost (DAC) is inversely related to one's divided attention ability. The areas of the DAC and FPR were calculated for each subject.

The mean divided attention costs, in units of FPR, were 577.8 for the young subjects and 565.4 for the elderly, respectively. This difference did not approach statistical significance, $t(30) = .69$. The duration adjustment procedure was intended to assure that performance of all subjects was comparable in the 100/0 and 0/100 conditions. If successful, one would not expect age differences in the size of the FPR. This was the case: The FPR values were 1,269.7 units for the young subjects and 1,330.7 for the older subjects, $t(30) = .32$. It should therefore make no difference whether DACs are compared in absolute terms or relative to each subject's FPR. To confirm this, relative DACs were calculated by dividing each subject's DAC by his or her FPR. The mean relative divided attention costs were .47 for both young and old subjects.

The major conclusion from this experiment is that there was no difference in the ability of young and old adults to divide their attention between two simultaneous tasks. Figure 1 suggests a very high degree of overlap between the functions for the two groups, and indeed, no significant age differences were found in two separate analyses.

Experiment 2

The purpose of the second experiment was to determine whether the findings of Experiment 1 would generalize to an experimental paradigm in which speed of response rather than accuracy was the variable of interest. It was argued that a criterion for an adequate test of age effects on a divided attention task is that age differences in performance under single-task conditions must be controlled. The first experiment produced the result that when such differences were equated there was no age difference under dual-task conditions. In the tachistoscopic task of Experiment 1 performance of the two age groups was equated by varying exposure duration. This sort of manipulation is obviously impossible for reaction time tasks. However, in reaction time tasks a way of controlling for these initial differences is to use each subject's single-task performance as a base and calculate divided attention effects as a ratio of dual-task performance. This allows judgment of each subject's dual-task performance relative to his or her own baseline.

Informal pilot data revealed that on the tasks chosen for this experiment it was virtually impossible for a subject to systematically vary the relative emphasis given to the two tasks. Therefore only one dual-task condition could be run, and the subjects were given no instruction about how much importance should be attached to each task. This usually creates a problem of not being able to separate differences in divided attention ability from differences in resource allocation strategies. This problem is particularly severe when the two dependent variables have dissimilar scales. If, for example, divided attention costs older subjects two units more than the young on Task A, but costs the young one unit more than the old on Task B, it is fair to say that the older adults are penalized more by the demands of divided attention only if a unit on Task A is worth more than half a unit on Task B. However, since the present experiment uses the same real-time measurement scale for each of the two concurrent tasks, it is reasonable to assume that any loss in performance on one task will be compensated for by an equal gain in performance on the other task.

Method

Subjects. Sixteen young adults (mean age, 18.6; range, 18–20) and 16 older adults (mean age, 68.7; range, 60–82) participated in a single 1-hr. experimental session. The subjects were chosen from the same population as in Experiment 1, but none had participated in that experiment. Older subjects were paid $5 for their travel and participation, whereas young subjects received extra course credit. Each group contained 6 males and 10 females. All subjects reported that they were in good health, and all were right-handed.

Mean raw scores on the WAIS Digit Symbol subtest were 71.1 for the young adults and 44.4 for the older adults, $t(30) = 6.43$, $p < .001$. Mean scores for the final 20 items on the WAIS Vocabularly subtest were 19.5 and 29.5 for the young and old subjects, respectively; $t(30) = 3.51$, $p < .01$.

Apparatus. The apparatus in this experiment was identical to that in the previous experiment except that visual stimuli were displayed on a Hewlett-Packard Model 1311A screen and subjects received auditory signals through a set of Koss PRO/4AA headphones.

Procedure. Two different tasks, manual reaction time (RT) and repetitive keying (key), were performed either separately or concurrently. In the RT task, the word *ready* appeared on the screen to initiate each trial, and at a random time within a 30-sec interval a single auditory signal was presented. The subject responded to the signal by depressing a button on the left keyboard with the index finger of the left hand. Each block consisted of 10 such trials. The key trials began with a seven-digit number appearing on the screen for 3 sec. It was then replaced by the first digit in the sequence, which served as a cue for the subject to begin entering the sequence of digits on the right keyboard with the fingers of the right hand. As the subject entered each digit, it was replaced on the screen by the next digit in the sequence. Immediately upon completion of the sequence the first digit in the sequence reappeared on the screen, and the subject repeated the sequence. A trial consisted of four runs through the sequence, but only the final three were used in the analyses. There were 10 trials in each block. The amount of time between successive responses was recorded as the interkey interval (IKI). Two different sequences were used in the experiment (2486359 and 7614853), but each subject retained the same sequence throughout the session.

In the dual-task condition, the subject had to enter the digit sequence with the right hand while responding to the auditory signals with the left hand. The experimental session began with two blocks of each task alone, with half of the subjects in each age group beginning with the key task and half beginning with the RT task. This was followed by four dual-task blocks and finally two more blocks of each task alone. Inspection of the data revealed a sizeable practice effect between the first and second key blocks. Therefore the first key block was considered practice, and to retain counterbalancing, both the first and final key blocks were excluded from subsequent analyses.

Results and Discussion

The mean reaction times for the young and old subjects were 231 msec and 260 msec, respectively, in the single-task condition, and 401 msec and 509 msec, respectively, in the dual-task condition. For the repetitive keying task the mean interkey intervals were 254 msec and 403 msec in the single-task condition for the young and old subjects, respectively. The comparable values in the dual-task condition were 281 msec and 450 msec, respectively. Identical 2 (age) × 2 (condition) ANOVAS were performed on the data from the two tasks. For the RT task, there were significant ($p < .05$) effects of age, $F(1, 30) = 14.11$, condition, $F(1, 30) = 257.67$, and Age × Condition, $F(1, 30) = 9.36$. For the key task, there were also significant ($p < .05$) effects of age, $F(1, 30) = 25.47$, condition, $F(1, 30) = 75.25$, and Age × Condition, $F(1, 30) = 4.27$. The absolute amount by which the older subjects were slowed in dual-task conditions was greater than the amount by which the younger subjects were slowed. This analysis, which is the one traditionally used to argue for age-related divided attention effects, in no way takes age differences under single-task conditions into account.

Figure 3 depicts the relationship between performance on the two tasks for each age group. It is possible to calculate the arithmetic mean of the divided attention cost as ½([RT dual − RT alone] + [IKI dual − IKI alone]). In terms of Figure 3, this may be represented as the mean length of the two dashed lines extending from the point that represents single-task performance to the horizontal and vertical coordinates of the point that represents dual-task performance. Woodworth (1938) argued that the geometric mean may be a more meaningful way to combine dual-task scores. He pointed out that if an individual has no divided attention ability at all, it would be possible to completely ignore one task and to perform the other task at a level equal to the single-task performance. The resulting combined dual-task measure (using an arithmetic computation) would be equal to half of the average of the two tasks when they were performed alone, and this would not accurately represent the subject's lack of time-sharing proficiency. Therefore, Woodworth reasoned, geometric means may be a more reasonable way of expressing combined dual-task performance. In terms of the present experiment this may be expressed as $([\text{RT dual} - \text{RT alone}]^2 + [\text{IKI dual} - \text{IKI alone}]^2)^{1/2}$. These values are depicted as the solid diagonal lines in Figure 3. Both divided attention cost measures were calculated for each subject. The mean values for the young and old subjects were 98 and 146, respectively, for the arithmetic computation, and 172 and 257, respectively, for the geometric computation. The age differences were significant for both the arithmetic and the geometric values, $t(30) = 2.09$, $p < .05$, and $t(30) = 2.03$, $p < .05$, respectively.

To take initial age differences on single-task measures into account, it is necessary to look at divided attention costs relative to single-task performance. The arithmetic computation for the average single-task performance is ½(RT alone + IKI alone). In Figure 3 these values are represented as the mean length of the horizontal and vertical dashed lines extending from the axes to the points indicating single-task performance. The geometric respresentation of single-task performance is $([\text{RT alone}])^2 + [\text{IKI alone}]^2)^{1/2}$; it is illustrated in Figure 3 as the length of the diagonal lines connecting the origin to the points indicating single-task performance. Relative divided attention costs were then calculated as ratios of each subject's divided attention costs to the average single-task performance for that subject. The mean arithmetic ratios were .41 and .44 for the young and old subjects, respectively. Mean geometric ratios were .52 for the young subjects and .56 for the old subjects. In neither case did the age difference approach statistical significance, $t(30) < 1$ in both cases.

In this experiment the absolute cost for divided attention was larger for the old subjects than for the young. When initial differences in single-task performance were controlled by examining dual-task performance relative to each subject's single-task performance, however, there was no age difference. The similarity of the relative divided attention cost measures in the two age groups is quite consistent with the results of the first experiment and provides some generalizability of those findings.

General Discussion

This study has argued that a significant amount of the literature that has purported to have demonstrated an adult age difference in the ability of individuals to divide their attention among two or more simultaneous tasks has failed to take several important considerations into account. The present exper-

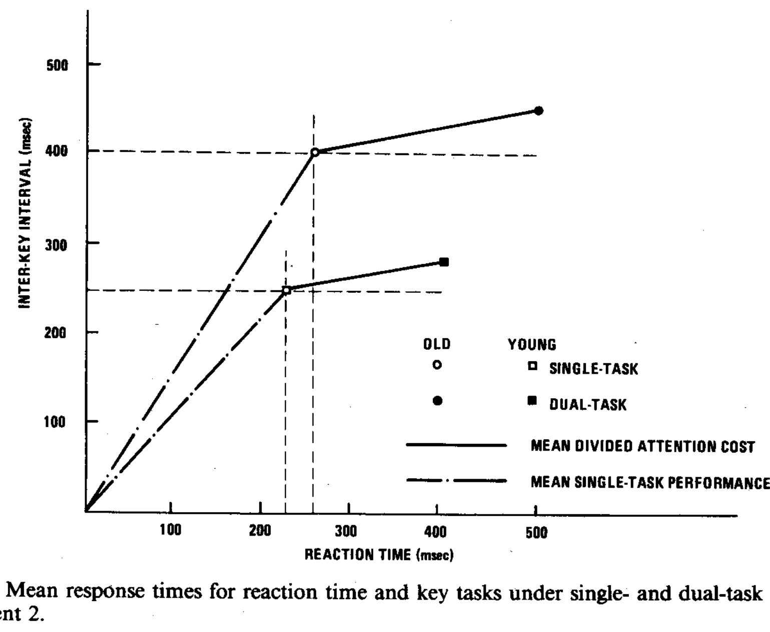

Figure 3. Mean response times for reaction time and key tasks under single- and dual-task conditions: Experiment 2.

iments were designed to address these issues, and therefore it is necessary to see how well the problems were overcome.

First, it was suggested that there should be an increase in the number of experimental paradigms used to study divided attention effects. Although it is impossible to satisfy this goal completely in a single study, the simultaneous visual displays used in Experiment 1 are unique in the research of adult age differences and contribute to the range of tasks that have been investigated. The second experiment was designed specifically to generalize the findings of the first experiment to a situation in which speed of response was being measured.

The second issue discussed was that most studies have found an age difference on single task measures, making dual-task performance difficult to interpret. In the first experiment in this study a duration adjustment procedure was used to find stimulus durations for each subject that would produce comparable performance levels for single-task conditions. Accuracies for the 100/0 condition (83.6% for the young subjects; 84.3% for the older subjects) and the 0/100 condition (85.1% for the young subjects; 85.3% for the older subjects) attest to the success of this procedure.

In making comparisons among POCs, it is essential that all subjects perform exactly the same task. It might be argued that giving older subjects a longer stimulus duration than younger subjects altered the nature of the task and thus invalidates the comparison of POCs. Although this is probably a matter of interpretation, we feel that this procedure did not change the task but merely established comparable baselines from which divided attention effects could be measured. The results of this experiment suggest that it is because of a failure to make this sort of manipulation that so much of the previous literature has suggested that older adults are less able to divide their attention than younger adults. The fact that the second experiment, in which baseline differences were controlled by examining relative age effects, produced similar results provides support for this conclusion.

Another issue that was raised was that many studies do not even collect single-task performance data. The 100/0 and 0/100 conditions fulfill this requirement in Experiment 1. Although these conditions did require responses for both arrays, the subjects were instructed to completely ignore one array. That accuracy on the "unattended" display was at chance level (50.2% across both ages and conditions) indicates that the subjects probably did not allocate any effort to those stimuli. In Experiment 2 there were conditions in which each task was performed alone.

The final issue discussed was the necessity to separate effects due to divided attention limitations from effects due to resource allocation strategies. The technique of examining entire trade-off functions rather than single data points eliminated this ambiguity in the first experiment. In the second experiment the comparable unit assumption suggested that if a subject sacrificed performance on one task, it would be directly compensated for by an equal gain in the other task. Thus, regardless of the way in which a subject allocated resources between the two tasks, the mean performance would be the same. One way of evaluating this assumption is to compare the variances of the two tasks. If the two tasks really do have comparable scales of performance, then it would be expected that their variances were similar. The pooled variances for the key and RT tasks in this experiment were 7,156.4 and 7,410.5, respectively. The parity of these values is supportive of the comparable unit assumption, and it therefore seems justifiable to use the mean of the two tasks to represent dual-task performance.

As the above discussion demonstrates, the two studies reported here substantially meet the suggested criteria for divided attention research. The first experiment was designed specifically to address the difficulties that have plagued previous research. In Experiment 2, some assumptions were required, but the similarity of the results in the two experiments suggests that they are quite reasonable ones. It may thus be concluded that in these pairs of tasks, at least, no age-related divided attention effect was found. The suggestion is that there are other processes (e.g., memory or perceptual impairments) that are responsible for the poorer performance of older subjects on individual tasks. However, given these initial performance discrepancies, older individuals are just as capable as younger adults at processing additional information. Given the conclusion of much of the earlier work, the results of these experiments are rather surprising. The present results are nevertheless quite clear, and the earlier conclusions were based on research that is difficult to evaluate because of the uncontrolled factors described earlier.

It was pointed out that one way that age differences in single-task performance have previously been controlled for, as in a study by Parkinson, Lindholm, and Urell (1980), was to match subjects on single-task measures. It was argued that this procedure may have selected subjects who were atypical of their age group, and it may thus have obscured real age differences in divided attention ability. In the present study subjects were not selected on any psychometric variable; however, it was found that in both experiments the older subjects had significantly higher WAIS vocabulary scores than the younger subjects. Although it is possible that this difference may partially account for the finding of no age difference in divided attention performance, two factors make this an unlikely hypothesis. First, the subjects in this experiment demonstrated the typical pattern of performance on single-task measures. The older subjects were slower on the reaction time tasks and required a longer tachistoscopic duration to achieve an accuracy comparable to that of the younger subjects. It was only on dual-task performance relative to these baselines that the age effect disappeared. Second, it was found that the WAIS Vocabulary scores were uncorrelated with divided attention measures. In the first experiment the correlation between WAIS Vocabulary score and divided attention cost was .12 for the young subjects and −.11 for the old subjects. In the second experiment the correlation between the vocabulary score and the relative divided attention cost was .18 for the young and −.15 for the old.

A second major contribution of this study is methodological. Although the arguments here have been couched in terms of adult age differences, they may be applied to any individual difference comparisons. There are many practical as well as theoretical needs for measures of divided attention ability, and the methodology described here provides a way of obtaining that information.

The question of controlling for differences under single-task is of particular relevance when one is concerned with measuring between-group differences in divided attention ability. Either the experimental conditions must be manipulated so that the initial performance under single-task conditions is equivalent for all groups, or some type of data transformation (e.g., the use of relative scores) must be employed. In the absence of these, between-group comparisons may be meaningless.

The difficulties associated with the confounding of divided attention limitations with resource allocation strategies is an issue any time that divided attention performance is assessed. The method that is usually employed is to collect only a single data point for each subject under dual-task conditions. In this situation it is often uncertain whether two points differ because of divided attention limitations or whether they are actually two points on the same POC function. Only when enough data have been collected so that the entire POC function may be constructed can differences be unambiguously interpreted.

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