Journal of Experimental Psychology:
Human Perception and Performance
1990, Vol. 16, No. 3, 523-537

0096-1523/90/$00.75

Age Differences and Similarities in the Effects of Cues and Prompts

Alan A. Hartley
Scripps College

James M. Kieley
Claremont Graduate School

Elizabeth H. Slabach
Purdue University

A series of 6 experiments investigated the use of cues and prompts by younger and older adults. Cues provide useful information about an impending target, even though the information is not always valid. Prompts provide an instruction about what aspect of the target is to be responded to. The costs and benefits of cues were most consistent with models in which the attentional resources that are shifted in response to the cue were as large or larger in older adults as they were in younger adults. The results with both cues and prompts converged on the conclusion that the time course of processing and using a cue or prompt is the same in younger and older adults. The attentional resources tapped by these procedures cannot be the diminished processing resource to which many age differences in cognitive performance are attributed.

Poorer performance by older adults is common in a wide variety of tasks with a wide variety of measures of performance. The observed differences in performance may be explained parsimoniously by assuming that there are changes with age in one or a few basic mental resources, such as attention, that are fundamental to many cognitive activities.

Theoretical difficulties with resource explanations for age differences on the basis of attentional resources have been pointed out (e.g., Salthouse, 1982, 1988a, 1988b, 1988c). It is possible, however, to proceed without theoretical consensus on attention as a cognitive resource. Procedures can be found that can be agreed on as tapping one or another aspect of attentional processing. If age differences can be demonstrated in those procedures, then the tasks will provide operational indicators of attention, and variables that affected the age differences in performance could then be explored. If age differences are found in some variants of a procedure but not in others, that will sharpen the denotative definition of the attentional processes that are affected by age. Patterns of correlation with other indicators, too, should provide converging evidence about the nature of attention and its contribution to complex cognition. This approach does not have the elegance of a program of research that proceeds from a strong theory of attention, but it does provide a way around the impasse identified by Salthouse and others.

The present research explores procedures that tap one characteristic of attention: that it can be shifted to facilitate the processing of an anticipated stimulus. If older adults were less likely than younger adults to shift attention in response to advance information, or if they shifted less rapidly or completely, then their performance would be impaired on many tasks. Rabbitt (1979; Rabbitt & Vyas, 1980) argued that the ability to shift attention declines as age advances, but only when the advance information requires active, memory-dependent processing. Passive, data-driven capture of attention by a stimulus was held to be unaffected by age. Although Rabbitt's distinction may be insufficient to account for the observed age-related changes in attentional selectivity (see Madden, 1984, 1985), it did provide a useful guide for choosing procedures in the present research.

There are at least three types of external stimuli that can result in shifts of attention—primes, cues, and prompts. A *prime* is a stimulus whose similarity to the target stimulus produces facilitation or inhibition of target processing. The prime and target may be identical or physically similar; they may be conceptually related; or they may be related only because they are assigned to the same response (Flowers & Reed, 1985). For example, presentation of one stimulus speeds the decision that the next stimulus is a word if both are meaningfully related words (Neely, 1976, 1977). A *cue* is a stimulus providing information that a certain stimulus or a stimulus with certain characteristics will subsequently appear as the target. For example, an arrow pointing to the visual field (left or right) in which a target is most likely to appear speeds detection of the target when it appears in the field

We gratefully acknowledge support for this research from National Institute on Aging (Grant AG01073), Claremont Graduate School, the Social Sciences Research Laboratory at the University of California, Irvine, and Scripps College Faculty Research Funds. Support for Alan A. Hartley during the preparation of this report was provided by National Institute on Aging Senior Postdoctoral Fellowship F33 AG05433 and the School of Psychology at Georgia Institute of Technology.

We are indebted to Heidi Cover, Minh Thu Le, Craig McKenzie, and Kirk Reynolds for assistance in data collection and to Mary Duncan, Myron Braunstein, and Michael Butler for material support. We are grateful, also, for the suggestions of Fergus Craik, John Flowers, Joellen Hartley, David Madden, Dana Plude, Wendy Rogers, and Timothy Salthouse.

Experiment 4 was part of a senior thesis submitted to Scripps College by Elizabeth H. Slabach. Preliminary reports of portions of this work were presented at the American Psychological Association meetings, Washington, DC, August, 1986; the Psychonomic Society meetings, Boston, MA, November, 1986, and Seattle, WA, November, 1987; and the conference on The Aging of Attention at the National Institute on Aging, November, 1987.

Correspondence concerning this article should be addressed to Alan A. Hartley, Scripps College, Claremont, California 91711.

indicated by the arrow and slows detection when it appears in the other field (Posner, 1980). A *prompt* is defined here as an instruction to attend to a particular aspect of a multidimensional stimulus or to carry out a particular operation on it. For example, when presented with a pair of digits, subjects could be prompted to add them or to subtract one from the other (Sudevan & Taylor, 1987), or, when presented with Stroop stimuli—color words printed in colored ink—subjects could be instructed to read the words or to name the ink colors.

Some elaboration on the defining characteristics of primes, cues, and prompts may help to distinguish them. Primes operate rapidly and automatically (at least, they have a substantial automatic component). They provide no information about the upcoming stimulus: that is, knowing what the prime is does not reduce uncertainty about what will appear next. For example, Rabbitt and Vyas (1980) presented sequences of digits and found that subjects' reaction times for digits that had been preceded by the same digit were faster than those that had been preceded by a different digit. The sequence, however, was random so that one digit conveyed no information about the next. Unlike primes, cues and prompts are consciously processed. Again, in contrast to primes, both cues and prompts reduce uncertainty about the upcoming stimulus: For an example of a cue, Nissen and Corkin (1985) presented arrows pointing to the likely location of the stimulus. The arrows were correct on 80% of the trials. Prompts, by definition, eliminate uncertainty because they inform the subject what dimension is to be processed. Finally, primes are neither useful nor necessary. Cues are useful to the subject, but they are not necessary. The subject's task in Nissen and Corkin's study was to respond when a light was detected. This could be done even if the arrow cues were ignored or omitted. Prompts are necessary because they inform the subject about the basis for a correct response.

Sudevan and Taylor (1987) used different terminology from that adopted here. What we term a cue, they labeled a prime, and what we term a prompt, they labeled a cue. Our choices are consistent with most prior research for both primes (see, e.g., Schachter, 1987) and cues (see, e.g., Posner, Snyder, & Davidson, 1980). Cue manipulations are sometimes described in terms of the hypothetical construct they are presumed to affect, expectancy (e.g., Lambert, 1987). Although cues may be said to induce short-term expectancies, the label expectancy will be reserved here for information about the stimuli that holds for an extended period of time: for example, knowledge that stimuli are twice as likely to occur in one position as in another over a block of trials (cf. Hoyer & Familant, 1987). In the absence of a commonly used term, we selected prompt because it conveys the immediate, transitory nature of the information better than alternatives such as instruction.

The research reported here is concerned primarily with the conscious and effortful (or memory driven) allocation and reallocation of attention rather than the automatic (or data driven) capture of attention. The experiments involve manipulations of cues and prompts rather than primes.

There have been several investigations of the effects of cues on performance in younger and older adults (Hoyer & Familant, 1987; Madden, 1983, 1984, 1985, 1986; Nissen & Corkin, 1985). The central question is whether there are age differences in the costs and benefits of cues. Correct or valid cues should produce a benefit or improvement in performance when compared with performance with no cue or an uninformative (neutral) cue. Incorrect or invalid cues should produce a cost or decrement in performance. Results have shown that the costs and benefits of cues are the same or larger for older adults as they are for younger adults, but this conclusion must be qualified because the cue could also have served as a prime in some studies (Hoyer & Familant, 1987; Madden, 1984, 1986; Nissen & Corkin, 1985) and because age differences may not emerge with short stimulus onset asynchronies (SOAs) between cue and target (Hoyer & Familant, 1987; Madden, 1985).

Although the ability of older adults to profit from instruction has been studied extensively, age differences in rapid responses to prompts have not. Schaie (1955) included a measure of speed of response to prompts in a battery of tests for behavioral rigidity. Even though the sample ranged in age from 17 to 79 years, no correlations between age and performance were reported. In Schaie's tasks there was no advance prompt. The instruction about how to process the target was conveyed by an aspect of the target itself. In order to examine processing of the prompt apart from the processing of the target, the present experiments presented a prompt at different prompt–target SOAs (cf. Sudevan & Taylor, 1987).

The next section is concerned with cues. Alternative models are developed for age differences in the processing of cues and results are presented from three experiments that test the predictions of the models. The following section does the same for prompts. Finally, the results are reviewed in an attempt to determine (a) whether the processing of cues and prompts is similar or different and (b) how that processing is affected by age.

Effects of Cues

According to James (1890/1950), attention is often characterized as a spotlight that illuminates whatever is selected for processing. Although this metaphor fits particularly well for attention to locations in visual space, it can be extended to other domains that need not be sensory. Attention has also been characterized as a resource that can be distributed over the range of stimuli (locations, objects, events, attributes, etc.) that might be processed (e.g., Jonides, 1980; Shaw, 1982, 1984). It is not often recognized that spotlight models represent a special case of resource models. The spotlight beam can be described as a distribution of resources in which there is a single area of finite extent with uniform resources that are greater than the remaining area. (There is debate about whether the aperture of the spotlight is variable, Eriksen & Yeh, 1985, and whether the dropoff in illumination at the edges is abrupt or gradual, Eriksen & St. James, 1986. Allowing for these possibilities produces a class of similar resource models.) If the restrictions of uniqueness (a single area), finiteness, and uniformity are lifted, then it is clear that for every resource model there is an isomorphic spotlight model.

If those restrictions are maintained, spotlight models account for experimental data less well than resource models (Jonides, 1980; LaBerge & Brown, 1989). Consequently, in the models developed here, attention is treated as a resource that can be differentially allocated to different locations or categories or stimulus attributes.

Attention should not be thought of as all the available resources. Certainly, nonattended stimuli can be processed so attention might best be characterized as the portion of resources that can be shifted in response to advance information to enhance marginally the processing of selected stimuli. If there are age differences in attention, they could be (a) differences in the amount of the resource, (b) differences in the efficiency with which the resource is allocated, or (c) differences in the speed with which the resource is allocated. The models for these differences will all proceed from a common assumption—that the fundamental speed of processing is slower in older than in younger adults. This assumption is consistent with a very large body of evidence (for reviews, see Birren, 1974; Cerella, 1985; Cerella, Poon, & Williams, 1980; Salthouse, 1982, 1985). For illustrative purposes (and without loss of generality), it is assumed that each processing step takes 50% longer for an older adult than for a young adult. This estimate is based on Salthouse's (1988c) finding that the average cost of each additional processing step was 1.55 times greater in older than in younger adults across a variety of tasks administered to the same subjects.

The models that are developed make the assumption that stimuli are processed in a series of homogeneous steps. In some models attention is assumed to affect all stages equally, in others it is assumed to reduce the number of steps. These assumptions are made to simplify the exposition, but the conclusions generalize to more specific models in which processing is cascaded or those in which attention has different effects on different steps. The concept of step here should not be confused with the notion of a processing stage such as encoding or retrieval.

Identical Resources Models

The first models assume that there are no age differences in either the amount or allocation of attentional resources in response to cues. Any age differences in performance, then, would be byproducts of the assumed age differences in speed of processing. Consider an *identical resources/fixed amount model* in which a cue causes an allocation of resources to the cued stimulus and away from the noncued stimulus. Assume that the additional resources cut the time to carry out each step in processing the stimulus by some constant amount. As an example, suppose (a) that the stimulus requires 10 processing steps, (b) that with no prior cue younger adults take 10 units per step (for a total reaction time of 100 units), and (c) that older adults take 15 units per step (for a total reaction time of 150 units). Now suppose the additional resources shifted in response to the cue cut the processing time by a fixed amount of 2 units per step (and, correspondingly, slow processing of the stimulus that was not cued by 2 units). Younger adults will respond to cued stimuli in 10(10 − 2) or 80 units and to noncued stimuli in 10(10 + 2) or 120 units, resulting in 40 units of costs plus benefits. Older adults will respond to cued stimuli in 10(15 − 2) or 130 units and to noncued stimuli in 10(15 + 2) or 170 units, for costs plus benefits of 40 units. Thus the identical resources/fixed amount model predicts that costs plus benefits will be equal for younger and older adults. If, however, costs plus benefits are expressed as a proportion of the reaction time to validly cued targets, they will be relatively higher for younger adults (.50) than for older adults (.31).

Next consider an *identical resources/fixed proportion model*, which is identical to the last model except that the resources brought to bear by the cue reduce the processing time at each step by some constant proportion. Suppose that proportion is .20. Under this model, younger adults will respond to cued stimuli in 10[(1 − .20)10] or 80 units and to noncued stimuli in 10[(1 + .20)10] or 120 units, for costs plus benefits of 40 units. Older adults will respond to cued stimuli in 10[(1 − .20)15] or 120 units and to noncued stimuli in 10[(1 + .20)15] or 180 units, for costs plus benefits of 60 units. Costs plus benefits will be larger for older adults in absolute units, but they will be relatively the same for the two age groups (in both, noncued stimuli require 50% longer). Similar predictions result if it is assumed that younger and older adults have the same resources and that application of attention reduces the number of processing steps in an *identical resources/fixed steps model*. The number of steps could be reduced because the cue has already conveyed partial information about the stimulus. Suppose that a cued stimulus can be processed with two fewer steps. Then younger adults would respond to a cued stimulus in (10 − 2)10 or 80 units and older adults in (10 −2)15 or 120 units. If shifting attention away from a stimulus increased the number of steps to process it (and the number of added steps was the same as the number saved with an attended stimulus), then younger adults would respond to a noncued stimulus in (10 + 2)10 or 120 units and older adults in (10 + 2)15 or 180 units. Again, costs plus benefits would be higher absolutely for older adults but the same relatively for both groups.

Lower Resources Models

These models assume that older adults have less of the attentional resource or that it is less effectively allocated in response to cues. For a *lower resources/fixed amount model*, assume that younger adults can allocate sufficient resources to reduce the time for each processing step by 2 units, but that older adults only allocate enough to reduce the time per step by 1 unit. Then younger adults will respond to cued stimuli in 10(10 − 2) or 80 units and to noncued stimuli in 10(10 + 2) or 120 units, for costs plus benefits of 40 units. Older adults will respond to cued stimuli in 10(15 − 1) or 140 units and to noncued stimuli in 10(15 + 1) or 160 units, for costs plus benefits of 20 units. Thus the lower resources/fixed amount model predicts that costs plus benefits will be smaller in older adults, but absolutely and relatively. Alternatively, under a *lower resources/fixed proportion model* we could assume that younger adults can transfer sufficient resources to reduce time per step by 20% whereas older adults can only achieve a reduction of 10% per step. Younger adults will respond to cued stimuli in 10[(1 − .20)10] or 80 units and to noncued stimuli in 10[(1 + .20)10] or 120 units, for costs plus benefits of 40 units. Older adults will respond to cued stimuli in 10[(1 − .10)15] or 135 units and to noncued stimuli in 10[(1 + .10)15] or 165 units. Again, costs plus benefits would be lower for older than for younger adults both absolutely and relatively. Under a *lower resources/fixed steps model* in which attention saved two processing steps for younger adults but only one step for older adults, younger adults would respond to cued stimuli in (10 − 2)10 or 80 units and to noncued stimuli in (10 + 2)10 or 120 units. Older adults would respond to cued stimuli in (10 − 1)15 or 135 units and to noncued stimuli in (10 + 1)15 or 165 units. Again, costs plus benefits would be lower for older adults. If no additional steps were added to noncued stimuli, there would be no costs, only benefits.

Lower Speed of Resource Allocation

The assumption can be added to any of these models that attentional resources are allocated more slowly in response to a cue in older than in younger adults. The predictions about costs plus benefits would be unchanged, it would simply take longer for the costs and benefits to emerge and asymptote in older adults. The predictions can be tested by varying the delay between the onset of the cue and the onset of the target.

All of these models assume the pool of resources is fixed at least over the short term and that resources transferred to a cued stimulus are transferred from noncued stimuli. If the pool of resources were not fixed and if attention represented additional resources that could be mobilized, there should be no costs for noncued stimuli. For example, in Nissen and Corkin's (1985) study, targets were presented at only two locations in the visual field. If attention represented a surplus resource that could be allocated to the cued location without expense to the noncued location, responses to the noncued location should have been as fast as when no informative cue was given. Instead they were slower. In fact, if attention were a surplus resource, a reasonable strategy would be to allocate at least some of it to the noncued location. This would produce a benefit for both cued and noncued location, which was, of course, not observed.

Notice, too, that these models are not specific to any particular stimulus domain. To extend the limits of generalizability, the predictions were tested both with cues to spatial location and with cues to category membership in the experiments that follow.

Experiment 1

In this experiment the targets were letters and numbers. The target was preceded either by an informative cue about whether it would be a letter or a number or by an uninformative cue that simply indicated a target would follow. To explore the time course of cue processing, we varied the delay between the onset of the cue and the onset of the target from 200 ms to 600 ms. The shortest SOA, 200 ms, was selected to explore times shorter than the fastest cue display used by Sudevan and Taylor (1987).

Method

Sixteen younger and 16 older adults participated in the experiment. The younger adults (7 men, 9 women) were students from the University of California, Irvine, who served for extra course credit. Their average age was 20.0 years (range, 18–22), and on a 1–10 scale with 10 as excellent health, their average self-rated health was 8.8. The older adults (3 men, 13 women) were volunteers from a Senior Nutrition Program and from organizations for retired persons in Claremont, California. Their average age was 70.9 years (range, 64–82) and average self-rated health was 9.1. Visual acuity was determined to be 20/30 or better either with normal vision or corrective lenses except for 2 individuals, 1 in each age group, who had acuity of 20/40. (Acuity of 20/100 would have been sufficient to discriminate the targets under the viewing conditions used.)

The stimuli were presented on the video display of an Apple II Plus microcomputer. Subjects were seated such that their foreheads were in contact with a guide strip located approximately 37 cm from the screen. At this viewing distance, characters subtended 0.74° of visual angle. Timing of presentations and reaction times was controlled by independently calibrated software routines. Each trial began with a fixation cross, presented at the center of the screen for 1,000 ms. This was followed by either the word LETTER, or the word NUMBER, or ??????, presented at the center of the screen. After an SOA of 200, 400, or 600 ms, depending on the condition, the cue was replaced by a target, also at the center of the screen. The target could be one of the letters A or B or the numbers 1 or 2. It remained on the screen for 1,500 ms or until the subject responded. The subject's task was to press a designated key with the left index finger if A appeared or a second key with the right index finger if 2 appeared and to withhold a response if B or 1 appeared. Although this response procedure does result in fewer data than if all stimuli were responded to, it was judged to reduce response confusion and simplify the task. The subject was told that the advance cues were usually but not always correct. In fact, LETTER was followed by A or B and NUMBER was followed by 1 or 2 on 80% of the trials. All four targets were equally likely after a ?????? cue. Responses to B or 1 and failures to respond to A or 2 were followed by a tone and the message ERROR displayed on the screen.

The trials were blocked by SOA. There were 90 trials in each block; the first 10 were discarded as practice. Of the positive (i.e., response required) trials after practice, 24 were validly cued, 6 were invalidly cued, and 16 were uninformatively cued. The trials with different cue–target combinations were randomly ordered within each block, with a new random order generated for each block for each subject. The order of SOAs was also randomly determined.

Results

Analyses of variance (ANOVAS) were carried out for reaction times, costs plus benefits, and proportions of errors. For reaction times and errors, age group (younger or older) was a between-subjects factor and the SOA (200, 400, and 600 ms), cue validity (valid, invalid, and neutral), and target (A and 2) were within-subjects factors. For each subject the geometric mean latency was calculated for all correct responses in each condition. The geometric mean is similar to the median in that it reduces the positive skewness in reaction time distributions, but it has the advantage that it retains information discarded by the median. The geometric mean has been used in other studies of aging and perception (e.g., Scialfa, Kline, & Lyman, 1987). An ANOVA showed significant effects of age, $F(1, 30) = 18.11, p < .001$, SOA, $F(2, 60) = 12.42, p < .001$, cue validity, $F(2, 60) = 36.77, p < .001$, and target, $F(1, 30) = 8.30, p < .01$. Average reaction times are shown in Figure 1. Older adults were slower than younger adults. Overall, reaction times remained about the same for SOAs of 200 and 400 ms but were longer when the cue preceded the target by 600 ms. The letter A was responded to more rapidly than the number 2. The cue had an effect: A valid cue speeded responses in relation to the neutral cue, whereas an invalid cue slowed responses.

Many researchers examine costs and benefits separately (e.g., Madden, 1984, 1985; Nissen & Corkin, 1985). Jonides and Mack (1984), however, argued that neutral cues may not provide an appropriate comparison. In addition to the information they convey, informative cues may lead to greater general alertness than do neutral cues. Furthermore, there is no guarantee that the time taken to process neutral and informative cues will be the same. Although the time between the onset of the cue and the onset of the stimulus is the same for neutral and informative cues, there is no guarantee that the time between completion of cue processing and stimulus onset is the same. For these reasons, Jonides and Mack (1984) recommend analyzing total costs plus benefits (measured by the difference between invalid and valid cue performance). We followed that recommendation in the results reported here: We calculated cost plus benefit for each subject in each condition by subtracting reaction time to a target preceded by a valid cue from reaction time to a target preceded by an invalid cue. Analysis of variance on costs plus benefits showed only a significant effect of age, $F(1, 30) = 4.46, p < .05$. Cost plus benefit was not affected by the S
of age and SOA (for both, $F < 1$). T
did not change with increasing cue a
group. When the costs plus benefits in milliseconds are expressed as a proportion of reaction time to validly cued targets,

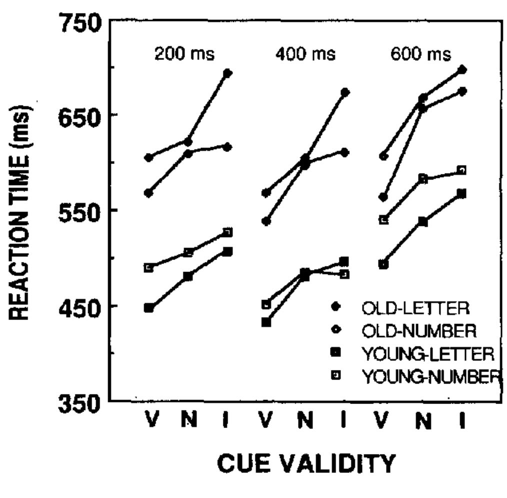

Figure 1. Mean reaction times in Experiment 1 as a function of age group, SOA, cue validity, and target (letter or number). (Mean standard error was 27.0 ms for older adults and 25.0 ms for younger adults. V = valid cue, N = neutral cue, I = invalid cue.)

older adults show twice the cuing effect (.10) of younger adults (.05).

Analysis of error proportions showed a significant main effect of SOA, $F(2, 60) = 5.32, p < .01$, and cue validity, $F(2, 60) = 10.67, p < .001$. Errors were comparable at SOAs of 200 and 400 ms ($M = .034$ and $.028$, respectively) and higher at 600 ms ($M = .075$). Errors were less likely with valid cues ($M = .025$) than with neutral ($M = .042$) or invalid cues ($M = .068$).

Discussion

The results are straightforward. Costs plus benefits were greater for older adults. They were present at the shortest SOA between cue and target and did not change in magnitude at longer SOAs for either age group. There was no evidence that the time course of cue processing was any different for younger than for older subjects. In retrospect, it would have been desirable to include even shorter SOAs in order to determine when costs and benefits begin to appear and to verify that they do so at the same time for both younger and older adults.

Experiment 2

In Experiment 1 cues were given about the category to which the target was likely to belong. In Experiment 2 cues were given about the visual hemifield in which the target was likely to appear. Again the interval between cue and target onset was varied. In this experiment, SOAs ranged from 100 to 500 ms. The shorter SOA was included in an attempt to detect effects that might have been missed in Experiment 1.

Ten older adults and 10 younger adults participated in this experiment. The older adults (3 men, 8 women) were recruited from the same population as in Experiment 1; they had an average age of 71.3 years (range, 67–79) and gave an average self-rating of health of 8.7. Younger adults (3 men, 7 women) were students recruited from the Claremont (California) colleges; they had an average age of 26.2 years (range, 23–33) and gave an average health rating of 8.9. Visual acuity was 20/30 or better for all subjects.

The procedures were generally similar to those of Experiment 1, except that the characters subtended 0.50° of visual angle. Each trial began with a fixation dot presented at the center of the screen for 1,000 ms. This was replaced by a cue that was displayed at the center of the screen for 100, 300, or 500 ms. If the cue was an arrow pointing to the left (<) or right (>), the target appeared in the indicated direction on 71% of the trials and on the opposite side on the remaining 29%. If the cue was a plus (+), the target was equally likely to appear to the left or right. The targets were the number 7 or the letter Z flanked by brackets (]7[or]Z[).[1] Targets were presented so

[1] The flankers were chosen following the conclusions of LaBerge and Brown (1989). Their results were consistent with the interpretation that a target without flankers does not require attentional filtering. Flankers such as those used in this study do require filtering but are much less difficult to process than alphanumeric characters that are high in featural similarity to the target, for example, T or 2.

that they were centered 2° or 4° to the left or to the right of fixation. Subjects were instructed not to move their eyes but to leave them fixated where the cross and cue had been, although Posner, Nissen, and Ogden (1978) found that results from trials with eye movements did not differ from trials on which subjects maintained fixation. The subject's task was to respond by pressing a key if the target contained a 7 and to withhold a response otherwise. Targets remained on until the subject responded or after 1,500 ms had elapsed.

The trials were blocked by SOA, and the order of blocks was randomly determined. There were 90 trials in each block, with the first 10 discarded as practice. On 20 of the cued, positive, postpractice trials, the target appeared on the cued side. On 8 of the trials, it did not. An additional 12 trials presented the uninformative cue. These types of trials were ordered in a different random sequence for each subject.

Results

ANOVAS were again carried out on geometric mean reaction times, costs plus benefits, and error proportions. Through a programming error, errors were not tallied for negative (no-response) trials. The error analysis was based on positive trials only. For reaction times and errors, age group was a between-subjects factor and SOA (100, 300, and 500 ms), cue validity (valid, invalid, and neutral), target direction (left and right of fixation), and target location (2° and 4° from fixation) were within-subjects factors. There were significant effects of age group, $F(1, 18) = 35.96$, $p < .001$; cue validity, $F(2, 36) = 7.34$, $p < .002$; and target distance, $F(1, 18) = 33.73$, $p < .001$. There were significant interactions of SOA and cue validity, $F(4, 72) = 3.35$, $p < .02$, and age and distance, $F(1, 18) = 9.96$, $p < .01$. The means are shown in Figure 2. Older adults were slower than younger adults. Targets at the more eccentric positions were responded to more slowly than targets nearer fixation, and this was particularly true for older adults. Analysis of costs plus benefits showed significant effects of the SOA, $F(2, 36) = 4.79$, $p < .02$, and of the Age Group interaction × SOA, $F(2, 36) = 3.40$, $p < .05$. Post hoc tests showed that costs plus benefits were significantly greater than zero for older adults at 300 and 500 ms, and for younger adults at 500 ms. Costs plus benefits for 300 and 500 ms SOAs, expressed as a proportion of valid cue reaction times, were higher for older adults ($M = .23$) than for younger adults ($M = .07$). Analysis of positive trial error proportions showed only an effect of cue validity, $F(3, 36) = 3.83$, $p < .002$; errors were lower with valid cues (.002) than with uninformative cues (.003) or invalid cues (.025).

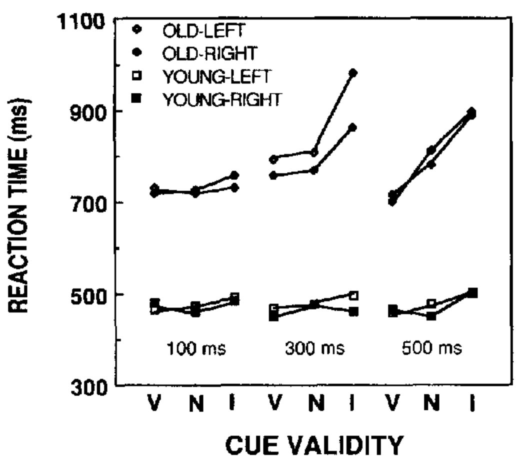

Figure 2. Mean reaction times in Experiment 2 as a function of age group, SOA, and cue validity. (Results from left and right target locations are collapsed. Mean standard error was 69.0 ms for older adults and 22.0 ms for younger adults. V = valid cue, N = neutral cue, I = invalid cue.)

Discussion

Costs and benefits appeared to emerge earlier for older adults than for younger adults; a cautious construal is that they appear at least as early in older adults. When they emerged, costs and benefits were larger in the older adults, both in raw score and relative units. The results for cuing of spatial location were consistent with those for category cuing in Experiment 1.

Experiment 3

In Experiment 2 attention was directed by a cue that appeared centrally at the point of fixation. The spatial location of the target can also be cued by a stimulus that appears in the periphery, in the field in which the target will appear. For example, a marker might be presented near the location of the impending target (e.g., Eriksen & Hoffman, 1973, 1974), or a box in which the target will likely appear may be brightened (Posner & Cohen, 1984). Jonides (1981) has shown that peripheral cues behave differently from central cues. Adding a memory load slows performance with a central cue but not with a peripheral cue. Subjects can consciously ignore a central cue; they appear unable to ignore a peripheral cue. A valid, but unexpected, peripheral cue improves performance even if it precedes the target by only 25 ms. A valid but unexpected central cue does not produce a benefit until an SOA of 100 ms. Jonides (1981) argues that peripheral cues induce shifts of attention more automatically than central cues. If central cues to spatial location result in what might be termed effortful, memory-driven shifts of attention whereas peripheral cues produce shifts that might be termed automatic and data driven, comparisons of younger and older adults may yield different patterns of results for the two types of cues. Experiment 3 repeated Experiment 2 but used peripheral cues to explore this possibility.

Method

Sixteen younger adults (7 men, 9 women) and 16 older adults (5 men, 11 women) were recruited from the same populations as Experiment 1. The younger adults had a mean age of 20.4 years (range, 18–24) and gave a mean health rating of 8.6. The older adults had a mean age of 69.1 years (range, 59–79) and gave a mean health rating of 8.9. All subjects had measured visual acuity of 20/30 or better, with the exception of 2 older adults with 20/40.

The procedures were generally similar to those of Experiment 2, with the exception that the characters subtended 0.74°. Each trial began with a fixation point at the center of the screen for 1,000 ms. This was followed by a bar marker that was centered 3° left or right of fixation or by a plus (+) appearing at fixation. The marker was displayed for 100, 200, 300, or 400 ms. The target was then presented, centered 2.2° left or right of fixation. The target was either a 7 or Z flanked by slanted lines (//7// or //Z//). The target was displayed for 200 ms. We instructed the subject to leave the eyes focused where the fixation cross had been and to respond to a 7 with a keypress and to withhold a response if a Z appeared. The subject had 1,200 ms to respond after target offset. On 75% of the trials with a bar marker, the target appeared in the same field as the marker; on the remaining 25% it appeared in the opposite field. When the plus appeared, the target was equally likely to appear in either field.

The trials were blocked by SOA and the order of blocks was randomly determined. There were 82 trials in each block, with the first 10 discarded as practice. There were 36 positive trials in each block, 18 validly cued, 6 invalidly cued, and 12 with the uninformative cue. The order of trial types was randomly determined for each block for each subject. During the practice trials the display times for cues and targets were gradually shortened until they reached the values that have been described.

Results

Analyses were again carried out on geometric mean reaction times, costs plus benefits, and error proportions. Age group was a between-subjects factor for the analyses of reaction time and errors, and SOA (100, 200, 300, and 400 ms), cue validity (valid, invalid, and neutral), and target location (left and right) were within-subjects factors. Analysis of reaction time showed significant effects of age, $F(1, 30) = 8.55$, $p < .01$; cue validity, $F(2, 60) = 155.99$, $p < .001$; and target, $F(1, 30) = 12.66$, $p = .002$; as well as significant SOA × Cue Validity interaction, $F(6, 180) = 4.55$, $p < .001$. The means are shown in Figure 3. The origins of these significant effects are more clearly seen in the analysis of costs plus benefits. Mean costs plus benefits are shown in Figure 4. There was only a significant effect of SOA, $F(3, 90) = 6.52$, $p = .001$. The age groups did not differ, $F < 1$. Although Figure 4 suggests an interaction, the effect of age and SOA fell short of significance, $F(3, 90) = 2.30$, $p = .08$. The costs plus benefits were significantly greater than zero for both age groups at all SOAs (smallest $t = 4.12$). Additional, but unplanned, comparisons among the means showed no significant differences in cost plus benefits as a function of SOA for the older adults; for the younger adults, costs plus benefits were significantly higher at 200 or 300 ms than at 100 ms. Costs plus benefits as a proportion of valid cue reaction time were slightly lower for older adults ($M = .15$) than for younger adults ($M = .18$). The analysis of error proportions showed only a significant effect of cue validity, $F(2, 60) = 3.50$, $p < .05$, reflecting slightly higher error rates for invalid cues ($M = .012$) than for valid ($M = .002$) or neutral cues ($M = .002$).

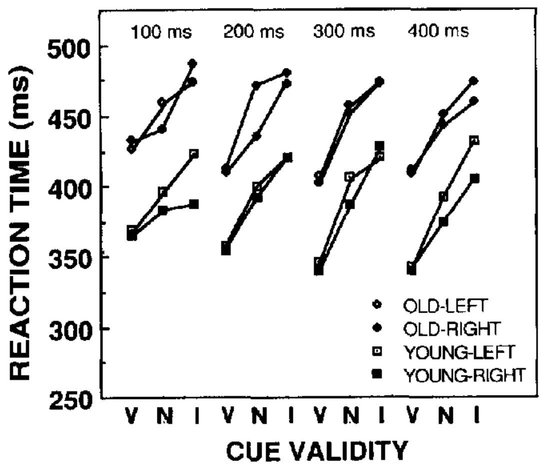

Figure 3. Mean reaction times in Experiment 3 as a function of age group, SOA, and cue validity. (Mean standard error was 16.5 ms for older adults and 10.7 ms for younger adults. V = valid cue, N = neutral cue, I = invalid cue.)

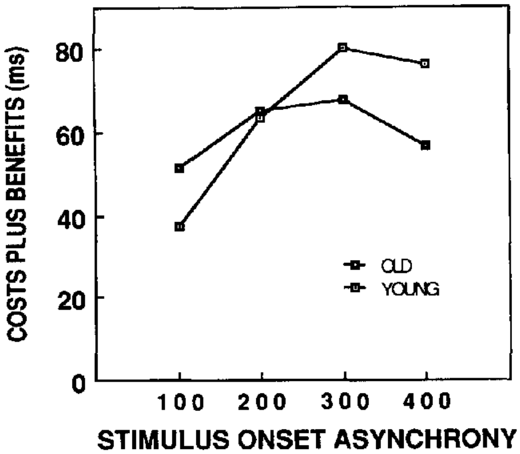

Figure 4. Costs plus benefits in Experiment 3 as a function of age group and SOA.

Discussion

The results of Experiment 3 are less clear than those of Experiments 1 and 2. The uncertainty comes from the marginally insignificant interaction of age and SOA in costs plus benefits. A conservative interpretation of those results would hold that costs and benefits follow the same time course in younger and older adults: They are present at 100 ms, grow until 200 to 300 ms, then asymptote. A liberal interpretation is that costs and benefits emerge earlier in older adults but show no further increase after 100 ms of cue exposure. Although they emerge later in younger adults, they continue to increase in size up to cue exposures of 300 ms, exceeding the costs and benefits of older adults. Even though the design was powerful enough to detect differences of 17 ms as significant, the conservative interpretation may be missing real age differences. By contrast, the liberal interpretation may be capitalizing on chance as it goes beyond even the results of the unplanned comparisons. What is certain is that the pattern of results in Experiments 1 and 2—with costs and benefits greater for older than for younger adults—was not found when attention was shifted in response to peripheral spatial cues. This is consistent with Jonides's (1981) assertion that central and peripheral cues are fundamentally different.

Discussion of Experiments 1, 2, and 3

To review, the identical resource models assumed that younger and older adults differed only in fundamental speed of processing and that there were no differences in the amount or allocation of attention. These models predicted that costs and benefits would be the same or greater for older adults than for younger adults when expressed as absolute reaction times and that they would be the same or less for older adults when expressed as a proportion of valid cue reaction times. The lower resource models assumed that older adults have reduced or less efficiently distributed attentional resources than younger adults. These models predicted that costs and benefits would be smaller in older adults than in younger adults, both absolutely and relatively. An additional assumption could be added to any of these models that attentional resources are deployed more slowly in older adults than in younger adults. If this were so, the cost and benefit pattern predicted by the model would emerge more slowly for older than for younger adults.

Experiments 1 and 2 produced comparable results, even though the cues were to category membership in one and to spatial location in the other. Costs and benefits were greater for older adults than for younger adults, both absolutely and relatively. Furthermore, the time courses of the effects of cues were the same for younger and older adults. For both groups in Experiment 1, costs and benefits were present at the shortest cue–target SOA and did not change in magnitude with longer presentations of the cue. In Experiment 2, costs and benefits emerged at least as early for older adults as for younger adults.

The results are clearly inconsistent with the models that assumed older adults have reduced attentional resources or that they allocate their resources more slowly. They are most consistent with the models that assumed that resources were identical and that the benefit of attention was to reduce the processing time per step by some fixed proportion or to reduce the number of steps required to process the target. The results are, however, only partially consistent with those models. Both models predicted that costs plus benefits expressed in absolute reaction times would be higher in older adults, but both also predicted that costs plus benefits expressed in relation to valid cue reaction times would be the same for both age groups. Within models of the type explored here, the results would be consistent only with models that assume older adults process more slowly but that they have more attentional resources available to be allocated to a cued stimulus. Attention would have to reduce time per step by a greater proportion or reduce the number of steps more for older adults than for younger adults. If one were to consider the set of possible models abstractly, such higher resource models would have the same status as the identical resource and lower resource models that were developed. It was the a priori requirement that only age deficits in attention could explain performance differences that removed higher resource models from consideration. The situation is analogous to a statistical test of a one-tailed hypothesis that results in what would have been a significant difference, but in the nonpredicted direction. We can reject lower resource and lower speed of allocation models. We cannot assert that higher resource models have been confirmed, but we can assert that future research should seriously entertain the hypothesis that older adults shift more attentional resources in response to cues than do younger adults.

Why might older adults appear to have more resources? One possibility is strategic (although the strategy need not be conscious). The cues in these experiments were not completely valid; on 20%–30% of the trials, the target was not the one that had been cued. The likely benefits of preparing for the cued stimulus must be traded off against the less likely, but substantial, costs of not preparing for the noncued stimulus. If the allocation of attention to the cued and noncued stimuli can be strategically controlled, then younger and older adults may choose different trade-offs. If younger adults gave higher weight to reducing the average costs of a noncued stimulus than did older adults, it would appear that the younger adults had less attentional resources at their disposal even though they may have the same or greater resources. Rather than a strategic choice by younger adults, it could be that the cue compels the allocation of attention to the cued stimulus in older adults and they cannot or do not override or adjust the allocation. These notions could be formalized as an *identical resources/different allocation* model. Such a model could account for the present results as well as a higher resources model. A strategic explanation for the age differences could be tested by using instructions or incentives to manipulate the trade-off experimentally.

Experiment 3 produced different results from Experiments 1 and 2. Costs and benefits in milliseconds were equivalent for younger and older adults; as proportions of valid cue reaction time, they were about 20% smaller for older adults. These results are consistent with an identical resources model. In Experiment 2 central cues produced greater costs and benefits for older adults than for younger adults; in Experiment 3 peripheral cues produced equivalent costs and benefits in the two age groups. This difference is consistent with Jonides's (1981) conclusion that central and peripheral cues exercise separable control over the allocation of attention. Both the central cues in Experiment 2 and the peripheral cues in Experiment 3 provided information about the likely location of the target. The peripheral cue, however, was similar to the impending target in that both cues were stimuli appearing in the same visual field. Thus a peripheral cue could prime the target as well as provide information about it. There is some evidence that semantic priming occurs as rapidly and effectively in older as in younger adults (e.g., Balota & Duchek, 1988). If the priming effects of peripheral cues are primarily automatic and if automatic processes are relatively unaffected by aging, then the absence of age differences with peripheral cues could be accounted for. If younger and older adults have identical resources, then when the allocation of those resources occurs automatically with a peripheral cue, the costs and benefits will be the same for both groups. When the allocation of attention is at least partially under strategic control with a central cue, the costs and benefits can differ.

In all three experiments, the time course of cue effects was arguably the same for younger and older adults. It could be that there are age differences at SOAs shorter than those used or that the temporal resolution was not fine enough to detect small differences. This is unlikely: The evidence is strong that cognitive processing proceeds more slowly in older adults. The slowing is reliable and substantial. That slowing should slow the processing of the cue significantly. Yet there was no evidence for this. Madden (1986) has presented evidence relevant to the present findings. In a series of studies, a secondary auditory reaction time task was used to examine age differences in the time course of processing. The primary task was letter search; the secondary probe tone occurred at various times before or after the onset of the primary display. Typically reaction times rose as the stimulus was presented, then fell back as processing was, presumably, completed. The time course of the reaction time slowing was extended by manipulations that should have increased processing, such as increasing the number of elements in the display. Although older adults had slower reaction times, the time course of processing was the same for both age groups and variables that altered the time course did not interact with age. In one study, a cue was presented on some trials. The presence or absence of the cue did not affect the equivalence of the time course of processing for younger and older adults. Thus there is additional evidence that the time course of activation may not be affected by age.

The present results bear some similarity to findings reported by Stanovich and West (1981) on the effects of context on word recognition. They asserted that anything that slows processing of the target word should increase the effects of context. For example, younger children and poorer readers, who are presumed to take longer to encode the target word, show greater context effects than older children and better readers. The analogy in the present research is that older adults take longer to process a target, so the cue should take longer to affect processing. The results are consistent with Stanovich and West's assertion. However, there is a problem with the analogy. Stanovich and West encouraged the subject to read the context at a comfortable pace. This should have allowed processing of the context to be mostly completed before the target appeared, but subject characteristics that slow the processing of the target should also slow processing of the cue. In the present research, the time available to process the cue was under the experimenter's control. If older adults processed the cue more slowly, that should have been apparent. It is unlikely that the process operating in Stanovich and West's studies can account for the present results.

The models that best account for costs and benefits proceeded from the assumption that there were large age differences in the rate at which the target was processed. How can this be reconciled with the conclusion that there were no age differences in the time course of processing the cue? We postpone an answer to this question until the General Discussion, where we attempt to develop a more comprehensive interpretation.

Effects of Prompts

A prompt is an instruction about what aspect of a target should be processed. If the target is available before the prompt, then all potentially relevant aspects of the target would have to be processed until the information from the prompt becomes available. Once the information is available, processing of irrelevant aspects can be stopped, and all resources can be shifted to the relevant aspect. (An alternative, but unlikely, possibility is that no processing of the target takes place until the prompt has been processed.) We can formalize these assumptions into models. Again, for illustrative purposes and without loss of generality, we frame the models by using specific values and the procedure used in Experiment 4. On each trial the subject saw a target, an X or an O that was colored either red or blue. At some SOA before the target, a prompt was presented to subjects to respond either to the letter or to the color of the target. Suppose that processing the color of a target alone would require 10 processing steps and that processing the letter would require the same number. Suppose also that each processing step requires 10 time units for a young adult and 15 for an older adult. If the prompt were fully processed before the target occurred, then a response to either aspect would require 100 units and 150 units, respectively. Suppose further that if the processing of the target begins before the information from the prompt is available, then both potentially relevant aspects are processed in parallel (or, equivalently, that they are processed serially but alternately). For a young adult then, after 20 units 1 processing step would have been completed for both color and letter; after 40 units, 2 steps would have been completed, and so on. Finally, suppose that as soon as the relevant aspect has been extracted from the cue, all processing of the irrelevant aspect ceases. Processing of the relevant aspect will become, in effect, twice as fast. Thus, the model can be characterized as one of cascaded processing of prompt and target. We develop two variants of the general model.

The first model, which may be termed an *identical time model*, assumes that the information from the prompt becomes available at some specified time after it is displayed and that this time is the same for younger and older adults. Suppose the information became available 120 time units after the processing of the target had started. A young adult would have completed 12 processing steps (at 10 units per step), 6 for color and 6 for letter. Four more steps would remain for the relevant dimension. The total time to respond would be (12)(10) + (4)(10) or 160 units. After 120 time units, an older adult would have completed 8 processing steps (at 15 units per step), 4 for color and 4 for letter. Six more processing steps would remain, for a total time of (8)(15) + (6)(15) or 210 units. If, instead, information became available for 60 time units into the processing of the target, a young adult would have completed 3 steps for each aspect and would have 7 steps remaining for the relevant aspect for a total time of (6)(10) + (7)(10) or 130 units. An older adult would have completed 2 steps for each aspect and would have 8 steps remaining for the relevant aspect for a total time of (4)(15) + (8)(15) or 180 units. Reaction times would asymptote when the information from the prompt was available before the target was processed. In this example, the asymptotic reaction times would be 100 time units for younger adults and 150 units for older adults. The predictions from this model are shown in Figure 5a. The important prediction is that the functions for the two age groups remain parallel across SOAs.

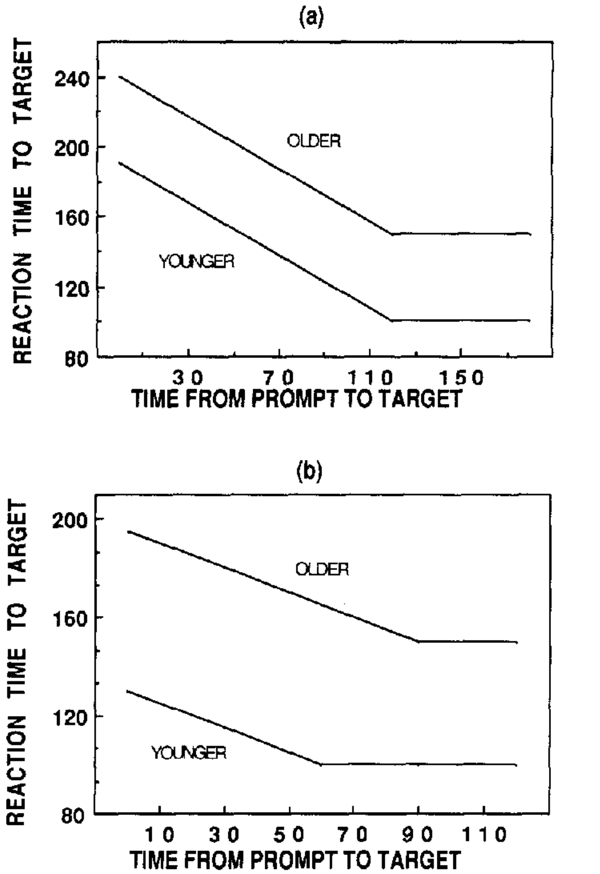

Figure 5. Panel a: Predictions of the identical time model of age differences in processing prompts. Panel b: Predictions of the identical steps model of age differences in processing prompts.

The second model, an *identical steps model*, assumes that processing the prompt requires the same number of steps for younger and older adults and that the processing is carried out at the characteristic rate for that age group. Suppose that processing the prompt requires six steps. Now, if the prompt is received 60 units before the target, a young adult will have completed processing of the prompt when the target arrives so a response will require (10)(10) or 100 units. An older adult will have completed four of the six steps required to process the prompt, so processing of the prompt will be completed 30 units after the target arrives. At that point, two steps in processing the target will have been completed, one each for color and letter. Nine will remain for the relevant aspect. The total time to respond will be (2)(15) + (9)(15) or 165 units. Response times for an older adult will be at asymptote for prompts presented 90 units or more before the target, or 30 units after a young adult. The predictions of this model are shown in Figure 5b. The important point is that an interaction of age group and SOA is predicted. The functions are parallel for prompts arriving well before the target or just shortly before, but with the later asymptote for older adults, the functions are not parallel for intermediate SOAs.

The models for cues made use of conditions in which no cue or an invalid cue was given. No comparable control condition is possible for prompts. Because the prompt conveys the response contingencies, it is not possible to give an invalid prompt, and, in the absence of the prompt, the subject cannot respond. In two of the experiments presented here, a control, unmixed block condition is possible in which all the trials in a block have the same relevant aspect, for example, color. Both of the models that have been presented would predict that reaction times in mixed blocks would be the same as those in unmixed blocks if SOAs are long enough for the prompt to be processed before the target is presented. That prediction turns out to be wrong; the following *Discussion* sections address ways in which the models are too simplistic, omitting important processes.

As was the case with cues, these models are not specific to any particular stimulus domain. To extend the limits of generalizability, we tested the predictions both with prompts to respond to one spatial location rather than another and with prompts to respond to the color or the letter in the scenario used as an example earlier.

Experiment 4

The procedure in this experiment was sketched in the preceding example. Targets were Xs or Os displayed in red or blue. At an SOA of 150, 450, or 750 ms before the target, a prompt was displayed that instructed the subject to respond to the letter or the color.

Method

Twenty younger adults and 20 older adults, each group with 7 men and 13 women, were recruited from the same populations as Experiment 2. The younger adults averaged 20.8 years (range, 18–30) and gave an average health rating of 8.6. The older adults averaged 70.8 years (range, 60–83) and gave an average health rating of 8.1. Visual acuity was not measured.

The experiment was controlled by an Apple II Plus microcomputer. A color video display was used (Taxan III RGB) rather than the monochrome display used in the previous experiments. The subject was positioned approximately 45 cm from the display, but head position was not constrained. Each trial began with a fixation cross centered on the display, presented for 1,000 ms. This was followed by the prompt, either the word LETTER or the word COLOR, centered on the display. At 45 cm, the letters in the prompts subtended 0.63° vertically and 0.51° horizontally. In the practice trials the prompt was displayed for 1,000 ms; in the experimental trials, for 150, 450, or 750 ms, depending on the condition. The target was then displayed and remained until a response was given. The target was an X or O displayed in red (magenta in the Applesoft color set) or blue (medium blue). It was centered in the display and subtended 2.16° vertically and 3.05° horizontally. The subject's task was to respond with a keypress to the aspect of the target identified by the prompt. Subjects responded to either red or X by pressing the P key that had been replaced with a red cap with a large black X; they responded to either blue or O by pressing the O key that had been replaced with a cap with a large black O. In addition, cards were placed above each key and showed the two responses assigned to that key. Trials were blocked by SOA. The first block was a practice block with an SOA of 1,000 ms. The experimental SOAs were randomly assigned to the second, third, and fourth block. The fifth, sixth, and seventh blocks reversed the order of the preceding three to create an ABCCBA design.

Within each block there were three sets, 10 trials with the LETTER prompt only, 10 trials with the COLOR prompt only, and 20 trials with a random mix of the two. Instructions preceding each set indicated whether the subsequent trials would be letter only, color only, or mixed. The order of sets within each block was randomly determined.

Results

ANOVAS were carried out on the geometric mean reaction times and on the proportion of errors. Age group was a between-subjects factor, and SOA (150, 450, and 750 ms), set type (unmixed and mixed blocks), and relevant aspect of the target (color and letter) were within-subjects factors. Analyses of reaction time yielded significant main effects of age, $F(1, 38) = 46.86$, $p < .001$; SOA, $F(2, 76) = 10.28$, $p < .001$; and set type, $F(1, 38) = 17.97$, $p < .001$. There were also significant interactions of SOA and set type, $F(2, 76) = 6.16$, $p < .005$, and of age and set type, $F(1, 38) = 4.50$, $p < .05$. The SOA × Set Type interaction occurred because reaction times dropped as the prompt was available longer in mixed sets, but were unaffected by SOA in the unmixed sets. The Age Group × Set Type interaction reflected the fact that the difference between mixed and unmixed sets was greater for older adults (M = 239 ms) than for younger adults (M = 96 ms). These differences are comparable for the two groups when expressed as proportions of the average reaction time in unmixed sets (M = .23 for older adults, M = .20 for younger adults). Neither the Age × SOA nor the Age × SOA × Set Type interactions were significant, $F(2, 76) = 2.61$, $p = .08$, and $F(2, 76) = 1.34$, $p = .27$, respectively. Because these interactions are important for discriminating the models, we examined the interaction of age and SOA for mixed sets only; it was not significant, $F(2, 76) = 2.22$, $p = .12$. The mean reaction times in Experiment 4 are shown in Figure 6. Analysis of error proportion yielded significant effects of SOA, $F(2, 76) = 5.36$, $p < .01$, and relevant aspect (color or letter), $F(2, 76) = 25.84$, $p < .001$. Errors decreased with SOA (M = .039 for 150 ms, .031 for 450 ms, and .025 for 750 ms) and were more likely for color (M = .059) than for letter (M = .016).

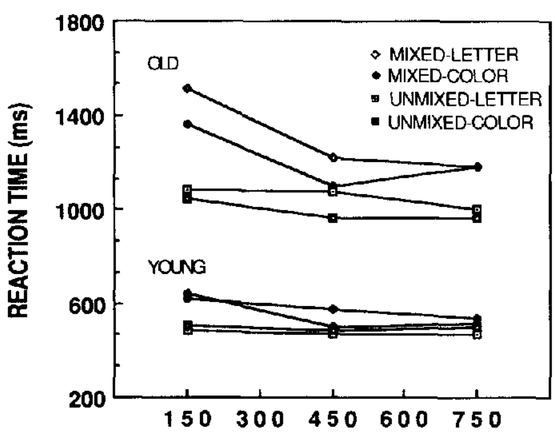

Figure 6. Mean reaction times in Experiment 4 as a function of age group, SOA, block (mixed or unmixed), and prompted aspect of the target (color or letter). (Mean standard error was 108.1 ms for older adults and 29.3 ms for younger adults.)

Discussion

The identical steps model predicted an interaction of age group and SOA, with older adults requiring longer SOAs to reach asymptote than younger adults; the identical time model predicted that they would reach asymptote at the same point and that there would be no interaction. The critical interaction of age and SOA for mixed sets was not significant. Nonetheless, the *F*s were sufficiently large and a test for interaction is sufficiently weak, particularly with a between-subjects factor, that the identical steps model should not be rejected without further test. In addition, the SOAs used in Experiment 4 were spaced widely and the grain may have been too rough to detect age differences in asymptote that actually existed. For these reasons, Experiment 5 was conducted, replicating Experiment 4, but with more closely spaced SOAs.

Experiment 5

Method

The methods used in this experiment were identical to those in Experiment 4, except that the postpractice trials used SOAs of 150, 250, 350, 450, and 650 ms. Twenty-five younger (mean age, 20.4 years; range 18–24) and 25 older adults (mean age, 71.3 years; range, 67–79) were recruited for the same populations as Experiment 4. There were 8 men and 17 women in each group. Mean health ratings were 8.6 for the younger adults and 8.7 for the older adults.

Results

Analysis of geometric mean reaction times yielded significant main effects of age, $F(1, 48) = 119.28$, $p < .001$; SOA, $F(4, 192) = 3.31$, $p < .02$; and set type, $F(1, 48) = 75.42$, $p < .001$. The SOA × Set Type and Age × Set Type interactions were also significant, $F(4, 192) = 4.43$, $p < .01$, and $F(1, 48) = 9.38$, $p < .01$, respectively. As in Experiment 4, the difference between mixed and unmixed blocks was greater for older adults (P = 226 ms) than for younger adults (M = 101 ms) in absolute units, but the differences were similar proportions of the reaction time in unmixed blocks (M = .239 for older adults, M = .222 for younger adults). The Age × SOA × Set Type interaction was not significant, $F(4, 192) = 1.39$, $p = .24$. The Age × SOA interaction was also tested for mixed sets only and was also not significant, $F(4, 192) = 1.243$, $p = .29$. The mean reaction times are shown in Figure 7.

Analysis of error proportions yielded significant effects of age, $F(1, 38) = 9.47$, $p < .005$; set type, $F(1, 38) = 4.06$, $p < .05$; and relevant aspect, $F(1, 38) = 7.53$, $p < .01$. Older adults (M = .081) made more errors than younger adults (M = .024); errors were more likely on mixed blocks (M = .064) than on unmixed blocks (M = .041); and classification by color (M = .078) produced more errors than classification by letter (M = .029).

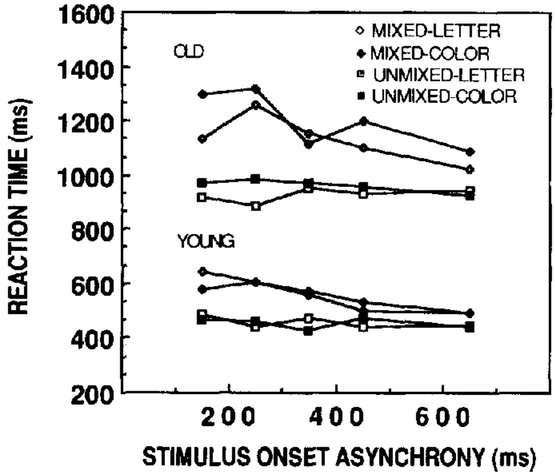

Figure 7. Mean reaction times in Experiment 5 as a function of age group, SOA, block (mixed or unmixed), and prompted aspect of the target (color or letter). (Mean standard error was 77.1 ms for older adults and 29.4 ms for younger adults.)

Discussion

Once again, the interaction of age group and SOA for the sets with mixed letter and color prompts was not found despite the fact that additional SOAs were explored. The results do not support the assumption that the processing of the prompt was being completed later in the processing of the target among older adults. It is possible that there were age differences in the processing of the prompt but that they were too small to be detected. However, this is unlikely. First, other measures of response slowing in this task show very substantial differences. For example, reaction times with unmixed sets were more than twice as long for the older adults than for the younger adults. Consequently, if processing of the prompt were lengthened comparably, it should have been detectable. Second, individual differences in the time to process the prompt should be relatively large in the older group. Yet, with the fine time grain, variances would have to have been quite small or the slowing would have become detectable.

An additional, important finding was that reaction times in mixed sets did not fall to the levels of unmixed sets even with long SOAs. With sufficient advance preparation, the task in the mixed blocks would appear to be no different from that in the unmixed blocks, so asymptotic reaction times should be the same. What are different are the response assignments. In an unmixed color block, for example, one key always means red and the other, blue. In a mixed block, the semantics of the keys changes at random from trial to trial. Stimuli appear that are associated with both keys, the correct one depending on the current prompt. For example, if the prompt LETTER precedes a red O, then the right-hand key is correct (for O) but the left-hand key would have been correct for that stimulus with the prompt COLOR. For other stimuli, it would appear unnecessary to process the prompt. For example, a red X would require a left-hand response no matter what the prompt. This raises the possibility that some individuals may do a fast test for the presence of a red X or blue O and, only if that test fails, analyze or review the prompt. This should result in a flat SOA function. If younger adults were more likely to adopt such a strategy, it would flatten the group SOA function for younger adults, but it would not change the inflection point. It is also the case that red Os and blue Xs should produce response competition. Reaction times would be affected both by the time course of prompt processing and by the time course of response competition. The time course of response competition could be different in older adults. This is unlikely in view of the results. The most likely case would be that both time courses are protracted in older adults. Yet, for the inflection point of the SOA function to be the same in older and younger adults as it was, the longer time course for response competition would have to be balanced by more rapid processing of the prompt.

These possibilities could have been evaluated more conclusively had a record been kept of the specific stimuli presented on each trial. Unfortunately, it was not. Instead, a small follow-up experiment was conducted with 6 older and 6 younger adults in which the stimuli were recorded. Only mixed blocks of trials were given. There were five SOAs; after a warm-up block at 1,000 ms, participants completed blocks of 60 trials each at SOAs of 200, 400, 600, and 800 ms. The blocks were randomly ordered. Older adults were slower, and response compatible trials ($M = 542$ ms) were reliably faster than response incompatible trials ($M = 601$ ms). There was no evidence of interactions of either the type of trial and SOA or of age, type of trial, and SOA (both $Fs < 1$). So, despite the plausibility of arguments that the original results may have been confounded by the operation of other processes, it appears the models developed for the processing of prompts are appropriate candidates both for response compatible and incompatible stimuli and for younger and older adults.

Experiment 6

In this experiment prompts were given about the spatial location that was to be responded to. Targets appeared in the left and right visual fields simultaneously, and an arrow that preceded the targets indicated the field on which the response was to be based.

Method

The subjects were the same individuals who participated in Experiment 1. The apparatus and viewing distances were the same as in Experiment 1. Each trial began with a fixation dot at the center of the video display for 1,000 ms. This was replaced by an arrow indicating whether the response should be based on the target to the left (<) or to the right (>). The prompt was displayed for 100, 200, 300, or 400 ms, then was replaced by the target display. The targets were the number 7 or the letter Z surrounded by slanted lines (//7// or //Z//). The targets were displayed so that the letter or number was centered approximately 3.7° left or right of fixation. The target display either had a 7 to the left and a Z to the right, or a Z to the left and a 7 to the right. We instructed the subject to maintain fixation where the prompt had been. The subject's task was to respond with a keypress if a 7 appeared on the side indicated by the prompt and to withhold a response otherwise. The target display was erased after 200 ms. The subject had an additional 1,000 ms to respond and the intertrial interval was approximately 1,000 ms.

The trials were blocked by SOA, and the order of blocks was randomly determined. There were 90 trials in each block, with the first 10 discarded as practice. On 40 of the postpractice trials, the positive target (7) appeared on the side indicated by the prompt; on the remaining 40, the negative target appeared on the prompted side. The two types of trials were ordered in a different random sequence for each subject. During the practice trials, the display times for prompts and targets were gradually shortened until they reached the values that have been described.

Experiment 6 included only what were termed mixed blocks in Experiments 4 and 5. Had blocks been included in which all the positive targets appeared on one side, the subjects could simply have shifted their gaze to that side. Because it was not possible to monitor eye movements, we could not have prevented that strategy. For this reason, unmixed blocks were not included.

Results

ANOVAS were carried out on the geometric mean reaction times and on the error proportions. Age group was a between-subjects variable, and SOA (100, 200, 300, and 400 ms) and prompted side (left or right) were within-subjects variables. Analysis of reaction times showed significant effects only for age group, $F(1, 30) = 20.45$, $p < .001$, and for SOA, $F(3, 90) = 37.16$, $p < .001$. The mean reaction times are shown in Figure 8. Older adults were slower and reaction times dropped with increasing SOA, but the difference between older and younger adults did not change. Analysis of error proportions showed the same significant effects. Older adults were more likely to make errors than were younger adults, $F(1, 30) = 6.36$, $p < .02$ ($M = .106$ and $M = .026$, respectively). Errors were more likely at 100-ms SOA ($M = .121$) than at 200 ($M = .047$), 300 ($M = .048$), or 400 ms ($M = .062$), $F(3, 90) = 7.41$, $p < .001$.

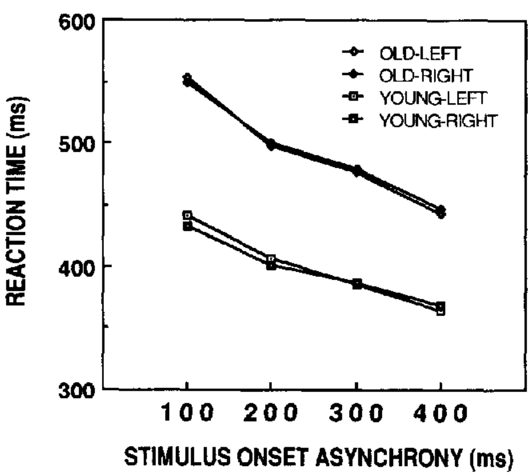

Figure 8. Mean reaction times in Experiment 6 as a function of age group, SOA, and prompted side (left or right). (Mean standard error was 21.7 ms for older adults and 12.8 ms for younger adults.)

Discussion

The absence of an interaction between age group and SOA indicates that the time course of processing and using the prompt was the same for younger and older adults. The results do not provide a clear test of the models, however, because neither group had reached asymptote at the longest SOA. In retrospect, it would have been helpful to have included a still longer SOA. It could be that an interaction would appear at SOAs longer than 400 ms. Nonetheless, the consistency among the results of the three experiments with prompts supports the conclusion that the prompts were processed equally fast by younger and older adults.

Discussion of Experiments 4, 5, and 6

Two models were proposed for the processing of prompts. The identical step model assumed that processing the prompt took the same number of steps for older and younger adults. Because older adults are assumed to execute each step more slowly, the information from the prompt would become available later for older adults than for younger adults. This model predicted that reaction times to targets would reach asymptotic level later for older adults. The identical time model assumed that the information about the prompt became available at the same time for younger and older adults. Both groups were predicted to reach asymptote at the same point, even though reaction times would be longer for the older adults. The results from Experiments 4 and 5 support the identical time model and fail to support the identical step model; results of Experiment 6 are, at least, consistent with this interpretation. This leads directly to the conclusion that extracting the information from a prompt occurs just as fast for older adults as it does for younger adults, despite the fact that the overt response requires substantially longer for older adults.

General Discussion

The results of these experiments replicate the well-established finding that older adults respond more slowly than younger adults. The striking aspect of the results is what they do not show: They consistently show no evidence that older adults allocate attention less effectively in response to a cue or that they process and use a cue or a prompt any less rapidly than younger adults. These conclusions are not specific to one type of task; they were demonstrated both with spatial locations and categories or aspects of target stimuli.

There is an inherent paradox in the type of model that best fits the results of both the cue and prompt experiments. All of the models proceeded from the widely held presumption that older adults process information more slowly. Yet the best fitting models incorporated assumptions that although processing of the target was carried out more slowly by older adults, there was no age difference in the rate of processing the cue or prompt. Cues and prompts must be registered and the relevant information must be extracted from them just as with target stimuli. Why should the processing be any different? Although the answer we propose is speculative, it is consistent with the results of these experiments and with other findings.

The end product of the processing of a target stimulus is an overt, physical response. The end product of the processing of a cue or prompt is an input to another processing stream, that of the target stimulus. It does not result in an overt response. If the extraction of information from a stimulus were unaffected by age but the use of that information to prepare and emit an overt response were slowed, we would expect that measures reflecting the time course of information extraction (and its use to modify ongoing processing) would not show age differences. Overall measures of time to respond would show differences. Alternatively, the response slowing may occur because older adults adopt a strategy of requiring greater certainty before committing themselves to a response (see Botwinick, 1984). Results have been reported that are inconsistent with generalized slowing of central processing but that are consistent with a selective slowing of response-related processes.

In a series of experiments mentioned earlier, Madden (1986) used a secondary tone reaction time task to examine the time course of processing demands. In one experiment, probes were presented after a cue about the possible positions in which a target could occur but before the onset of the target display. Probe reaction times were longer for older adults than younger adults, even though the measure used was the proportional increase in subjects' reaction time while performing the primary task in relation to a baseline of the secondary task done alone. For both older and younger adults, however, probe reaction times were elevated until 200 ms after the onset of the cue. They then dropped to asymptotic levels at 300 ms and beyond. If slowing of probe reaction times reflects increased processing demands, then processing of the cue is relatively more costly for older adults but they process it as rapidly as younger adults. In another experiment, probe reaction times were not affected for either older or younger adults by surrounding the target with flanking letters that were response incompatible. Reaction times to the target, however, were measurably lengthened, particularly for the older adults. This result is consistent with the explanation that parsing the display and extracting the identity of the stimulus in the critical position is independent of the processes of mapping the extracted information onto a response and that only the latter step is affected by aging. Finally, in a third experiment, Madden compared probe reaction times on trials for which no overt response was required on the primary task with other trials on which a response was required. When no response was required, there was little difference in the probe reaction times of younger and older adults. The added requirement of a response had no significant effect on younger adults but produced substantial slowing in the older adults. Madden's results are consistent with the interpretation that age differences in overall reaction time are due more to slowing in later decision and response stages of processing than to slowing in the extraction of information from the input.

Strayer, Wickens, and Braune (1987) reached similar conclusions from analyses of age differences in variants of the Sternberg memory search task. The task was to determine whether or not a probe item was a member of a memorized set. Typically, response latency increases with the size of the memory set and performance can be characterized by the intercept and slope of the function relating response latency and set size. They found the linear increase with latencies for an overt response and also with latencies of the P300 component of event-related potential recordings, as would be expected if increasing the number of items increased the amount of cognitive processing required. The slopes of the functions for overt responses increased monotonically with average group age, as though the same amount of processing required more time for older adults. Nonetheless, the slopes of the functions for P300 showed almost no change with increasing age. In addition, they found that manipulating the speed–accuracy trade-off through instructions affected reaction times but had no effect on P300 latency in any age group. From these and other considerations, Strayer et al. (1987) concluded that age differences in central memory search processes made a negligible contribution to overall differences in reaction time. A relatively large contribution was attributed to response criterion adjustment. This included not only a general conservative response strategy in older adults but also an apparent tendency to increase response criteria as the number of stimuli to be processed increased or as the type of stimulus became more difficult.

In summary, the results of the present experiments provide no evidence that attention as it is allocated in response to cues and prompts could be a resource that is reduced in old age and that it therefore could serve as an explanation for the decrements that are observed in cognitive performance. The results were well fit by models that assumed no difference (or even a difference favoring older adults). Moreover, the results converge with those reported by Madden (1986) and Strayer et al. (1987), and show that overall age differences in reaction time are more likely due to differences in response-related processes than to generalized central slowing.

References

Balota, D. A., & Duchek, J. M. (1988). Age-related differences in lexical access, spreading activation, and simple pronunciation. *Psychology and Aging, 3*, 84–93.

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

Botwinick, J. (1984). *Aging and behavior: A comprehensive integration of research findings* (3rd ed.). New York: Springer-Verlag.

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

Cerella, J., Poon, L. W., & Williams, D. M. (1980). Age and the complexity hypothesis. In L. W. Poon (Ed.), *Aging in the 1980s* (pp. 332–340). Washington, DC: American Psychological Association.

Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays.

Perception & Psychophysics, 14, 155–160.

Eriksen, C. W., & Hoffman, J. E. (1974). Selective attention: Noise suppression or signal enhancement. *Bulletin of the Psychonomic Society, 4,* 587–589.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225–240.

Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 583–597.

Flowers, J. H., & Reed, D. (1985, November). *Characteristics of visual context effects in visual classification tasks.* Paper presented at the meeting of the Psychonomic Society, Boston, MA.

Hoyer, W. J., & Familant, M. E. (1987). Adult age differences in the rate of processing expectancy information. *Cognitive Development, 2,* 59–70.

James, W. (1950). *The principles of psychology* (Vols. 1 & 2). New York: Dover. (Original work published 1890)

Jonides, J. (1980). Toward a model of the mind's eye's movement. *Canadian Journal of Psychology, 34,* 103–112.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.

Jonides, J., & Mack, R. (1984). On the cost and benefit of cost and benefit. *Psychological Bulletin, 96,* 29–44.

LaBerge, D., & Brown, V. (1989). Theory and measurement of attentional operations in shape identification. *Psychological Review, 96,* 101–124.

Lambert, A. (1987). Expecting different categories at different locations and spatial selective attention. *Quarterly Journal of Experimental Psychology, 39A,* 61–76.

Madden, D. J. (1983). Aging and distraction by highly familiar stimuli during visual search. *Developmental Psychology, 19,* 499–507.

Madden, D. J. (1984). Data-driven and memory driven selective attention in visual search. *Journal of Gerontology, 39,* 72–78.

Madden, D. J. (1985). Adult age differences in memory-driven selective attention. *Developmental Psychology, 21,* 655–665.

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

Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. *Memory & Cognition, 4,* 648–654.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Nissen, M. J., & Corkin, S. (1985). Effectiveness of attentional cueing in older and younger adults. *Journal of Gerontology, 40,* 185–191.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3–25.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Posner, M. I., Nissen, M. J., & Ogden, W. C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick, Jr., & E. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 137–157). Hillsdale, NJ: Erlbaum.

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109,* 160–174.

Rabbitt, P. (1979). Some experiments and a model for changes in attentional selectivity with old age. In F. Hoffmeister & C. Muller (Eds.), *Brain function in old age: Evaluation of changes and disorders* (pp. 82–94). New York: Springer-Verlag.

Rabbitt, P., & Vyas, S. M. (1980). Selective anticipation for events in old age. *Journal of Gerontology, 35,* 913–919.

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

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 400–426). New York: Van Nostrand Reinhold.

Salthouse, T. A. (1988a). Effects of aging on verbal abilities: Examination of the psychometric literature. In L. L. Light & D. M. Burke (Eds.), *Language and memory in old age* (pp. 17–35). New York: Cambridge University Press.

Salthouse, T. A. (1988b). Resource-reduction interpretations of cognitive aging. *Developmental Review, 8,* 238–272.

Salthouse, T. A. (1988c). The role of processing resources in cognitive aging. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood* (pp. 185–239). New York: Springer-Verlag.

Schachter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.

Schaie, K. W. (1955). A test of behavioral rigidity. *Journal of Abnormal and Social Psychology, 51,* 604–610.

Scialfa, C. T., Kline, D. W., & Lyman, B. J. (1987). Age differences in target identification as a function of retinal location and noise level: Examination of the useful field of view. *Psychology and Aging, 2,* 14–19.

Shaw, M. L. (1982). Attending to multiple sources of information: I. The integration of information in decision making. *Cognitive Psychology, 14,* 353–409.

Shaw, M. L. (1984). Division of attention among spatial locations: A fundamental difference between detection of letters and detection of luminance increments. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 109–121). Hillsdale, NJ: Erlbaum.

Stanovich, K. E., & West, R. F. (1981). The effect of sentence context on ongoing word recognition: Tests of a two-process theory. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 658–672.

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

Sudevan, P., & Taylor, D. A. (1987). The cuing and priming of cognitive operations. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 89–103.

Received June 10, 1988
Revision received August 3, 1989
Accepted August 4, 1989 ■