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Evidence for the Selective Preservation of Spatial Selective Attention in Old Age

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Younger and older adults were tested in 2 versions of the Stroop color-word task: a color-block version in which the color word was adjacent to a color block and a color-word version in which the word was printed in color. An advance cue preceded the stimulus by 100 to 300 ms, indicating where it would appear. Age differences were small on the color-block version and large on the color-word version. These results are consistent with the speculation that posterior brain attention systems responsible for selecting a spatial location are relatively well preserved with advancing age but that anterior brain attention systems responsible for selecting a line of processing are compromised.

Evidence from the neurosciences and neuropsychology indicates that there are at least two distinct attention systems in the human brain (see Posner & Petersen, 1990, for a review). One system involves posterior structures such as parietal cortex, the pulvinar nucleus of the thalamus, and the superior colliculus. A variety of evidence indicates that this system is concerned with focusing attention on locations in visual space. For example, neglect, a failure to attend to objects in one part of space, can result from damage to the parietal lobes (for a review of neglect syndromes see Heilman, Watson, & Valenstein, 1985). The superior colliculi have been implicated in inhibition of return: the phenomenon that it is more difficult to redirect attention to a location where it has recently been than to an unvisited location (Posner, Rafal, Choate, & Vaughan, 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989). LaBerge and Buchsbaum (1990) have used positron emission tomography (PET) scans to compare conditions requiring that attention be focused on one object in a field of objects with conditions in which no attentional filtering is required. They found greater activity in the pulvinar thalamic nuclei than in nearby areas concerned with general visual processing in the focused attention conditions. Activity in the two areas did not differ when no filtering was required. In contrast, the second attention system involves anterior structures such as the frontal cortex. Evidence indicates that this system is concerned with attending to one of several possible streams of cognitive processing rather than one of several possible locations in space. For example, using PET scans Corbetta, Miezin, Dobmeyer, Shulman, and Petersen (1990, 1991) found greater activation in posterior, extrastriate areas than in other areas when the task was to detect a change in one stimulus dimension (e.g., shape). When the task was to detect a change in any one of three dimensions, there was greater activation in anterior cingulate cortex than in other areas. In the former case, the aspect of the stimulus to be processed could be selected in advance; in the latter case, it could not. Pardo, Pardo, Janer, and Raichle (1990) obtained PET scans of subjects doing a Stroop color-word task. The task is to name the color in which a word is printed. The word may name the color, the color and word are congruent, or it may name a different color, the color and the word are incongruent. In this task, the processing of the color must be selected and the processing of the word inhibited, particularly on incongruent trials. Pardo et al. (1990) found heightened activity in the anterior portion of the cingulate cortex on incongruent trials in comparison with congruent trials. There are also speculations about how the anterior and posterior systems might interact (see Goldman-Rakic, 1987).

A defensible summary of a fair amount of evidence about aging and attention is that age differences are relatively small when performance depends on selecting a specified location in visual space and ignoring others; however, age differences are relatively large when performance depends on selecting one line of processing and ignoring others. For example, age differences are relatively small when there is no uncertainty about the location of a target and much larger when the location is uncertain (Plude & Hoyer, 1986; Wright & Elias, 1979). Hartley, Kieley, and Slabach (1990) and Nissen and Corkin (1985) have found that the benefits of a correct cue to the location in which a target will occur and the costs of an incorrect cue are as large or larger for older adults as for younger adults. Furthermore, Hartley and McKenzie (1991) and Hartley, Kieley, and McKenzie (1992) have found that older and younger adults were equally able to broaden or narrow the spatial extent of the focus of attention. In contrast, when attention must be directed to two different tasks, age differences are characteristically large (for recent reviews, see Hartley, 1992; Madden, 1990a; Madden & Plude, 1993; McDowd & Birren, 1990). Age differences are

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also large on the Stroop task, in which attention is directed to both the color and the word, even though the meaning of the word is irrelevant to the task (Cohn, Dustman, & Bradford, 1984; Comalli, Wapner, & Werner, 1962; Panek, Rush, & Slade, 1984).

The neuropsychological evidence is consistent with a dissociation of functions that are based on the anterior and posterior attention systems. The patterns of age-related differences are consistent with differential change in the two attention systems. The present research is based on two premises. First, the posterior attention system is responsible for selecting one location and filtering information from other locations, whereas the anterior attention system is responsible for selecting one line of processing and filtering others. Second, age-related change in the ability to selectively attend to a location is small, whereas age-related change in the ability to selectively carry out a line of processing is large. A developmental dissociation in performance on attention tasks is neuropsychologically plausible. Moreover, it should be possible to demonstrate such a dissociation directly. If two variants of the same task can be found, one allowing spatial filtering of irrelevant information and one not allowing filtering, then age-related differences should be relatively much smaller when spatial selection of relevant information and filtering of irrelevant information are possible than when they are not. This was the approach followed in the present research. Methods used in the earlier neuroscientific research guided the selection of the task and the creation of two variants. The hypothesis is motivated by the speculation that the operation of the posterior attention system is relatively unimpaired by normal aging, whereas the operation of the anterior attention system shows substantial effects of aging. It is important to note, however, that the test is of the psychological hypothesis rather than of the physiological speculation that motivated it.

In the present research, I used two versions of the Stroop (1935) task. A color and a word were presented at fixed positions in either the left or right visual field. A short time before the Stroop stimulus, the individual saw a cue about the location in which it would occur. As usual, the task was to name the color, ignoring the word (a color name) that also appeared. The purpose of the cue was to assure that attention was oriented to the location of the Stroop stimulus on each trial and to control the time available for the shift and engagement of attention.

In the first version of the task, the stimuli were color blocks with a color word (printed in black) above or below. This color-block version of the task resembled that used by Kahneman and Chajczyk (1983). A cue appeared 100 to 300 ms before the stimulus, indicating whether the color block would be presented in the left or right visual field. If the advance cue allows focusing of attention on the location of the color block, filtering out all or most of the word, the Stroop effect should be reduced. To the extent that the word can be filtered out, the response should not be facilitated when the color and the color word agree (e.g., a blue block with the word blue above) and it should not be hindered when they disagree (e.g., a blue block with the word green above).

The second version of the task was very similar except that the stimuli were standard Stroop stimuli: color words printed in color (the color-word version). In this version of the task, using the advance cue to do spatial filtering is of no value. Other resources must be brought to bear to inhibit semantic processing of the word.

In addition, two types of cues were used. One was a rectangle that outlined the location at which the target would occur: the block in the color-block version of the task and the word in the color-word version. The second type of cue was an arrowhead, presented at fixation, pointing to the field in which the target would appear. Jonides (1981) found that the first type of cue appeared to prime the target location, rapidly and automatically summoning attention. It was as though attention were pulled to the location by these peripheral cues. The second type of cue appeared to result in a slower, more effortful allocation of attention to the cued location. It was as though attention were pushed to the location by central processes. Effects of peripheral, or exogenous, cues appeared earlier than those of central, or endogenous, cues; shifts of attention in response to endogenous cues could be consciously countermanded, whereas shifts in response to exogenous cues could not. More recently, Müller and Rabbitt (1989) have presented evidence that there is a single attention-orienting mechanism that can be activated either by higher level voluntary control or by more primitive reflexive control.

Predictions

Analyses were carried out on both the mean reaction time and the Stroop effect: the difference between the mean reaction time when the color and the color word were incongruent and the mean reaction time when the color and color word were congruent. The predictions can be stated most simply in terms of the Stroop effects. In the color-block task, if age differences in spatial filtering are small, the Stroop effects should be similar in older and younger adults. In contrast, in the color-word task in which spatial filtering is of no help, the Stroop effects should be much larger than in the color-block task, and this should be particularly true for older adults. In terms of the physiological speculation, when the task draws heavily on the posterior brain attention system, small age differences are expected; when the task draws on the anterior brain attention system, large differences are expected.

The two types of cues, endogenous and exogenous, were used because both have been used in previous research. Although reaction times to endogenous cues were expected to be longer than those to exogenous cues, no age differences were expected. Müller and Rabbitt (1989) speculated that reflexive orienting of attention to exogenous cues was dependent on superior colliculus systems related to saccadic eye movements, whereas voluntary orienting of attention to endogenous cues was dependent on the posterior parietal cortex. Evidence summarized by Posner and Petersen (1990) is also consistent with this speculation. Both mechanisms would be part of the posterior attention system, and, under the present hypothesis, the manipulation of the type of cue would not be expected to interact with age. Consistent with this prediction, Hartley et al. (1990) found comparable age differences for endogenous and exogenous cues.

The manipulation of the stimulus onset asynchrony (SOA) between the cue and the target was intended to assure that attention was shifted to the target on each trial; the presence of effects of SOA would confirm that attention was being affected. Predictions can also be made about age differences and the time course of cue utilization. Generally, the longer the cue is available the more benefit should be realized. Theories that postulate a generalized slowing of processing with advancing age (e.g., Cerella, 1985b, 1991; Myerson, Hale, Wagstaff, Poon, & Smith, 1990) would predict that the effects of the cue would appear more slowly for older adults. Madden (1990b) and Hoyer and Familant (1987) have presented results that may be consistent with this prediction. In contrast, Hartley et al. (1990) found similar time courses in younger and older adults. Notice that generalized slowing would also predict differential lengthening of the effect of the slower, endogenous cues in older adults, a result not found by Hartley et al.

Method

Participants

Sixteen younger adults participated as one of several options for obtaining extra credit in an introductory psychology course. There were 13 women and 3 men; mean age was 18.3 years (range = 18–21) and mean education was 12.7 years (range = 12–15). The mean for self-rated health, using a 10-point scale on which 10 was *excellent*, was 7.8. Median visual acuity, tested with a Snellen chart viewed with both eyes at a distance of 6.1 m (20 ft), was 20/25 (range = 20/15–20/30). Sixteen community-dwelling older adults volunteered to participate. There were 12 women and 4 men; mean age was 75.9 years (range = 68–86) and mean education was 14.1 years (range = 8–18). The mean health rating was 8.1, and median visual acuity was 20/30 (range = 20/20–20/40). The older adults received a cash payment for their participation. All participants were screened for use of prescription medications that might affect cognitive performance. They were screened for defective color vision using Dvorine plates. They were also screened for any difficulty in reading the color words at the test distance by having them read the 20/40 line from the Rosenbaum Pocket Vision Screener (which was substantially smaller than the words). None was eliminated for any of these reasons. Data from 1 younger adult in one condition were lost because of a computer hardware failure. Because of the within-subjects nature of the design, all data from that subject were excluded from the analyses reported here.

Design

Each participant was tested in four blocks of trials, defined by the combination of the two versions of the task (color block and color word) and the two types of cues (peripheral and central). Within the four blocks, both cued and uncued trials were presented with indicators preceding the targets at SOAs of 100, 150, 200, 250, and 300 ms. The order of the color-block and color-word versions of the task was counterbalanced across participants. The order of the two types of cues was counterbalanced across participants; each participant either completed central then peripheral cues within one version and peripheral then central cues within the other version or the reverse.

Procedure

Stimuli were presented and responses and response latencies were collected using an Apple II+ microcomputer with a Taxan RGB color display. The background color throughout the experiment was white. Responses were given by using two adjacent keys at the far right of the keyboard. The original keycaps were replaced with a blue cap on the left and a green cap on the right. The participant's right index finger rested on the blue key and the second finger on the green key. Participants were seated so that they were approximately 37 cm from the display. They were asked to maintain that distance from the display throughout the testing session; they were reminded before each condition not to shift closer to or farther from the display. Head position, however, was not fixed.

Practice. Each version of the task was preceded by 100 practice trials. The extensive practice blocks were intended to establish firmly the key-to-color assignments. No cues were presented in the practice blocks. For the color-block version, practice trials consisted of a black fixation cross (subtending 0.73° in width by 0.85° in height) centered on the screen followed 1,000 ms later by either a blue or a green rectangle outlined in black (subtending 3.65° in width by 1.10° in height). The rectangle was at the same vertical elevation as the fixation cross and was located to the left or right, with the inner edge 1.22° from the fixation cross. The fixation cross remained present when the rectangle appeared. The participants were instructed to press the key corresponding to the color of the rectangle as quickly as possible but without making errors. Errors were signaled by the word *error* at the bottom of the screen and a tone. In the color-word version, the rectangles were the same black outline boxes with the words *dog* or *cat* printed in blue or green within the box. In this version, the participants were instructed to press the key corresponding to the color in which the word was printed. Because the intention was to study the effects of shifts of attention rather than shifts of gaze, participants were instructed to keep their eyes fixed on the fixation cross throughout the experiment. They were told that only by maintaining fixation on the cross could they avoid missing the color stimuli because those would occur unpredictably to the left or right of fixation. Participants were observed by watching the reflection of their eyes on the glass of the display to assure that they were not moving their eyes. In pilot tests with individuals who deliberately moved their eyes to the target locations, eye movements could be reliably detected.

Color-block conditions. In these conditions, the displays were similar to the practice trials except that a color word, blue or green, was printed in black directly adjacent to the color block, either above or below it. The words subtended 0.73° in height and 2.56° (blue) or 3.17° (green) in width. The words were positioned such that the nearest contour was 1.71° from the center of the fixation cross. The cue was presented following the fixation cross. After the SOA for that trial, the blue or green block outlined in black was presented. The block remained on the screen until the participant responded or until 1,500 ms had elapsed without a response.

Color-word conditions. The procedures were identical to those in the color-block conditions except that the targets were the words *blue* or *green* printed in blue or green centered in the black outline rectangles. The words subtended the same angles as those in the color-block conditions.

Peripheral-cue conditions. In these conditions, a black outline rectangle was presented at the location where the color block or word printed in color would appear. The cues were perfectly valid. That is, the target always appeared at the location of the cue.

Central-cue conditions. In these conditions, the left or right side of the fixation cross was filled in to form a black arrowhead pointing to the field in which the color block or word would appear. Cues were, again, perfectly valid.

General procedures. There were 120 trials in each of the four conditions. These consisted of 24 cued trials at each of the five SOAs.[1] All

[1] There were actually 240 trials in each of the four conditions. On 120 of the trials both sides were cued. The intention had been to create a noncued condition with which performance in the cued conditions could be compared. Both rational analysis of the task and examination

possible combinations of the side on which the target appeared (left or right), the color (blue or green), and the word (blue or green) were used equally often. A software clock, independently calibrated to 1 ms accuracy, was started when the raster scan reached the top of the screen and began to present the target display; the clock was stopped when a keypress was sensed. Reaction times longer than 1,500 ms, shorter than 200 ms, or from trials on which errors occurred were discarded. Error trials were not replaced. Rest breaks were given every 60 trials within each condition as well as between conditions.

Results

Reaction Times

A preliminary analysis was carried out on the mean correct reaction times for each participant in each combination of task version (color block and color word), cue type (peripheral and central), congruity (color and word congruent and incongruent), and SOA. Overall, mean reaction times were longer for older (M = 585 ms) than for younger adults (M = 425 ms), $F(1, 29) = 34.07$, $p < .001$. There was a significant main effect of the version of the task, $F(1, 29) = 116.96$, $p < .001$, which was qualified by an Age Group × Task Version interaction, $F(1, 29) = 18.77$, $p < .001$. Reaction times in the word task were slower than those in the block task, more so for older adults (Ms = 640 and 531 ms) than for younger adults (Ms = 448 and 402 ms). There was a significant main effect of congruity, $F(1, 29) = 79.30$, $p < .001$. This was qualified by an Age Group × Congruity interaction, $F(1, 29) = 15.91$, $p < .001$, a Task Version × Congruity interaction, $F(1, 29) = 28.88$, $p < .001$, and an Age Group × Task Version × Congruity interaction, $F(1, 29) = 11.10$, $p = .002$. The reaction time difference between congruent and incongruent stimuli was greater for the word task than for the color-block task, and this was more true for older adults (mean difference of 76 ms in the word task and 22 ms in the block task) than for younger adults (mean differences of 25 ms and 12 ms). There was a significant main effect of SOA, $F(4, 116) = 33.59$, $p < .001$. This was qualified by a Task Version × SOA interaction, $F(4, 116) = 6.52$, $p < .001$, a Congruity × SOA interaction, $F(4, 116) = 10.66$, $p < .001$, and a Task Version × Congruity × SOA interaction, $F(4, 116) = 8.02$, $p < .001$. The Age Group × Task Version × Congruity × SOA interaction was not significant, $F(4, 116) = 2.09$, $p = .087$. The mean reaction times as a function of age group, task version, congruity, and SOA are given in Table 1. Finally, there was a main effect of cue type, $F(1, 29) = 19.61$, $p < .001$. Exogenous cues resulted in shorter reaction times (M = 494 ms) than did exogenous cues (M = 516 ms). This effect was not qualified by any significant interactions. No other effects in the analysis of variance were significant.

Stroop Effects

Many of the effects in the analysis of reaction times can be seen more clearly by examining the Stroop effects. These were calculated for each participant for correct trials in each condition by subtracting the mean reaction time when the color and word were congruent from the mean reaction time when they were incongruent. The mean Stroop effects are shown in Figure 1. For the analysis of variance, age group (young or old) was a between-subjects factor and task version (color blocks and color words), cue type (peripheral or central), and SOA (100, 150, 200, 250, and 300 ms) were within-subjects factors.

There were significant effects of age, $F(1, 29) = 15.91$, $p < .001$, and of task version, $F(1, 29) = 28.88$, $p < .001$. These effects were qualified by a significant Age × Task Version interaction, $F(1, 29) = 11.10$, $p = .002$. Stroop effects were small in the color-block version (Ms = 22 ms and 12 ms for older and younger adults, respectively); the age groups did not differ significantly, $t(29) = 0.52$, *ns.* They were larger in the color-word version, particularly for older adults (Ms = 76 ms and 25 ms for older and younger adults, respectively); the age difference was significant, $t(29) = 2.66$, $p < .01$, one-tailed. (The mean Stroop effect was significantly greater than zero in both the color-block version, $t[29] = 1.79$, $p < .05$, one-tailed, and the color-word version, $t[29] = 5.20$, $p < .001$.) There was also a main effect of SOA, $F(4, 116) = 10.66$, $p < .001$, and an SOA × Task Version interaction, $F(4, 116) = 8.00$, $p < .001$. Examination of Figure 1 shows that the size of the Stroop effect dropped from 100 to 150 ms and then increased at 200 and 250 ms, dropping thereafter. This effect was present in both versions but was exaggerated in the color-word version. Tests of the simple main effect of SOA for each task version separately showed a significant effect for the color-word version, $F(4, 116) = 13.47$, $p < .001$, but not for the color-block version, $F(4, 116) = 1.56$, *ns.* A posteriori pairwise comparisons of the means in the color-word condition using Tukey's procedure showed that the Stroop effects at 250 ms SOA were significantly higher than those at 100 or 150 ms SOA and that Stroop effects at 200 ms SOA were significantly higher than those at 150 ms SOA. Thus, the statistical analyses confirm the apparent effects of SOA only in part.

Proportional Reaction Times

The central hypothesis was that age differences in the Stroop effects would be much larger in the color-word task than in the color-block task. The analysis of Stroop effects found a significant age difference on the color-word task but not on the color-block task. This may, however, have been due to low statistical power. Although the Stroop effects for older adults were approximately twice those of younger adults on the color-block task, the two age groups differed by only 10 ms. In Cohen's (1992) terminology, this is a small effect size (d = 0.22). Sample sizes of over 300 per group would be needed to achieve a power of .80 to detect a population difference of this size as significant.[2] (In

of the data suggested that the intention was not realized. Because there were only two target positions, it would be possible to direct attention to both as Müller and Findlay (1987) and Eriksen and Yeh (1985) have shown. Examination of the data from individual subjects suggested that some spread attention across the two locations, whereas others shifted attention to one side or the other. Because of the uncertainty about the effect of the manipulation, the trials on which both sides were cued have been excluded from the analysis and the discussion.

[2] In the review process, the argument was raised that the failure to find a significant age difference in the Stroop effects in the color-block task may have been due to a statistical artifact, lower reliability of measurement in that task. Contrary to that argument, split-half reliabilities were .56 for the color-block conditions and .63 for the color-word conditions.

Table 1
Mean Reaction Time (and Standard Deviation) in Milliseconds as a Function of Age Group, Task Version, Congruity, and Stimulus Onset Asynchrony (SOA)

	Cue-target SOA									
	100		150		200		250		300	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Color-block task										
Older adults										
Congruent	536	92	549	91	506	83	509	99	499	90
Incongruent	573	74	557	100	525	86	535	99	520	92
Younger adults										
Congruent	403	57	409	66	384	70	387	62	394	60
Incongruent	431	68	413	69	400	70	403	73	390	72
Color-word task										
Older adults										
Congruent	622	97	615	103	597	86	585	94	589	115
Incongruent	683	103	658	115	686	122	709	138	652	117
Younger adults										
Congruent	456	69	450	55	427	65	424	79	421	52
Incongruent	467	92	448	87	463	74	467	74	457	79

contrast, the effect size in the color-word task was large, d = 0.89, resulting in a power of approximately .80.) The critical question is not whether there was no age difference on the color-block task but, rather, whether the increase in the Stroop effect from the color-block task to the color-word task was relatively larger for older adults than for younger adults. To explore this, a new dependent measure was calculated for each participant in each condition: the mean correct reaction time in the color-word condition as a proportion of the mean correct reaction time in the color-block condition. For example, the ratio would be found of the reaction time for the color-word task with an exogenous cue, 200 ms SOA, and incongruent word to the reaction time for the color-block task in the same combination of conditions. This measure reflects the relative slowing when spatial filtering is not possible. It also has the desirable property of removing the effects of any general, proportional slowing in older adults. If reaction times in older adults are some fixed multiple of reaction times in younger adults, then, if a manipulation increased reaction time, it would be expected to produce a greater increase in absolute reaction time in older than in younger adults. Using the color-block reaction time as a baseline means that age-related effects must be disproportionate to be significant. Some authors have argued for more complex relations than simple, linear, proportional slowing (e.g., Cerella, 1985b, 1991; Myerson et al., 1990). The functions they have proposed are sufficiently close to a linear relationship that, in real-world data sets, a proportional transformation such as that used here should compensate for general slowing.

For the analysis, the factors were the same as those in the analysis of the untransformed reaction times, except that task version was no longer included (because the new measure was the ratio of the reaction times in those two conditions). There was a main effect of age, $F(1, 29) = 8.27$, $p = .008$. The proportional slowing was greater for older adults ($M = 1.22$) than for younger adults ($M = 1.12$). That is, older adults were 22% slower in the color-word task than in the color-block task, whereas younger adults were only 12% slower. There was also a main effect of congruity, $F(1, 29) = 24.86$, $p < .001$. This was qualified by an Age Group × Congruity interaction, $F(1, 29) = 8.79$, $p = .006$. The slowing in the color-word task affected incongruent stimuli more than congruent stimuli, and this was more true for older adults (*M*s = 1.27 for incongruent and 1.16 for congruent) than for younger adults (*M*s = 1.14 and 1.11, respectively). Finally, there was a significant main effect of SOA, $F(4, 116) = 6.61$, $p < .001$, qualified by a Congruity × SOA interaction, $F(4, 116) = 7.59$, $p < .001$. The means for the interaction are given in Table 2. Computation of the simple main effect of SOA for incongruent and congruent stimuli separately showed that it was significant for incongruent stimuli, $F(4, 116) = 7.32$, $p < .001$, but not for congruent stimuli, $F(4, 116) = .48$, *ns.* Within the incongruent stimuli, a contrast comparing the proportional reaction times at 100 and 150 ms SOA with those at 200, 250, and 300 ms SOA was significant, $F(1, 116) = 26.75$, $p < .001$.

Errors

An analysis of variance was carried out on the percentage of errors with age group as a between-subjects factor and task version (color block or color word), cue type (peripheral or central), trial type (congruent or incongruent), and SOA as within-subjects factors. The mean percentage of errors in each condition is given in Table 3. Errors occurred on 2.73% of the trials for older adults and 3.79% for younger adults; the difference was not significant, $F(1, 29) = 0.83$, *ns.* Peripheral cues produced a lower error percentage than central cues (*M*s = 2.77 and 3.75, respectively), $F(1, 29) = 5.47$, $p = .03$.

Incongruent words and colors produced a higher error per-

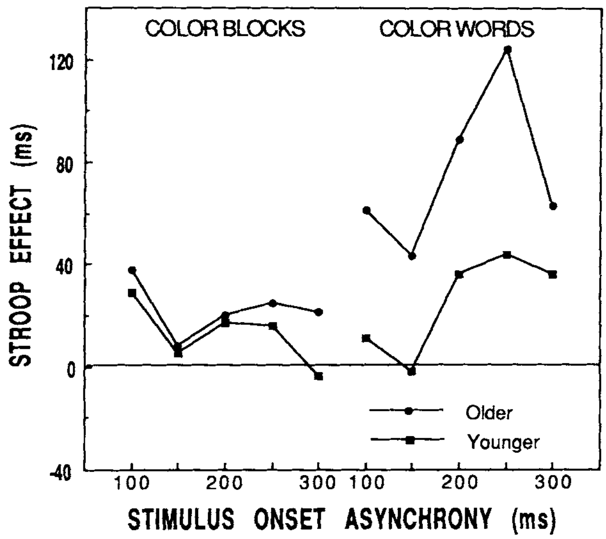

Figure 1. Stroop effects (incongruent minus congruent reaction time in milliseconds) as a function of color-block versus color-word task, age group, and stimulus onset asynchrony.

centage than congruent words and colors (*M*s = 4.10 and 2.41, respectively), $F(1, 29) = 23.06$, $p < .001$. There was a Congruency × Task Version interaction, $F(1, 29) = 6.26$, $p = .02$. In the color-word version, the difference between incongruent and congruent trials was 2.25%; in the color-block version, it was 1.15%. There was a Congruency × Age Group interaction, $F(1, 29) = 7.18$, $p = .02$, and a Congruency × Age Group × Cue Type (peripheral or central) interaction, $F(1, 29) = 5.26$, $p = .03$. Across cue types, the effect of congruity on errors was greater in older adults than in younger adults. However, for the older adults, the effect of congruity was greater with central cues than with peripheral cues, whereas the reverse was true for the younger adults.

No other effects or interactions were significant.

Discussion

Age-Related Effects

The principal prediction was that, when processing of the color word could be suppressed through spatial filtering, age differences in Stroop effects would be small; when the location of the word could not be spatially filtered and, instead, an intruding line of processing had to be suppressed, age differences would be large. Age differences were small and nonsignificant in the color-block version of the task in which the color word was spatially separated from the color block; they were substantial in the color-word version of the task in which the color and the color word were integrated. This result is not an artifact of the complexity effect, the finding in many tasks that age differences in reaction time increase in direct proportion to the time required to execute the task. The proportional increase in reaction time from the color-block to the color-word task was greater for older adults than for younger adults. Both younger and older adults were slowed when the word was physically integrated with the color, but the absolute increase in reaction time for older adults was more than would be expected if the two age groups showed comparable proportional slowing. This establishes that the Age × Task Version interaction in reaction time cannot be accounted for fully by the fact that the color-word task was simply more difficult and, so, would have required proportionately more time. The proportional slowing for younger adults was similar for incongruent words (14%) and congruent words (11%); reaction times were slower in the color-word task so that the Stroop effect for reaction times in the color-word condition was larger than in the color-block condition, but was not disproportionate to the general increase in reaction times. This was not true for the older adults, for whom there was a large difference in the proportional slowing for incongruent words (27%) and congruent words (16%). Thus, for older adults, but not for younger adults, the Stroop effect was disproportionately exaggerated by combining the color and the word in the same location.

Previous research had shown that exogenous cues have an effect sooner than endogenous cues. Here, exogenous cues were boxes appearing at the location of the color stimulus; endogenous cues were arrows appearing at fixation and pointing to the field in which the stimulus would appear. Exogenous cues did produce shorter reaction times, but the effect of the type of cue did not interact with any other variable. For example, Stroop effects did not emerge any earlier with exogenous cues. The cue effect was small (22 ms) and the grain of the SOA variable was coarse (SOA varied in 50-ms steps), so there may have been effects that were not detected. There was no Age Group × Cue Type interaction. This is consistent with the prediction that,

Table 2
Mean Reaction Time (and Standard Deviation) in Color-Word Conditions as a Proportion of Reaction Times in Color-Block Conditions

	Cue-target SOA									
	100		150		200		250		300	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Color-word pair										
Congruent	1.15	0.10	1.12	0.11	1.15	0.11	1.13	0.12	1.13	0.11
Incongruent	1.15	0.16	1.14	0.13	1.24	0.18	1.26	0.22	1.22	0.16

Note. SOA = stimulus onset asynchrony.

Table 3
Mean Percentage Error (and Standard Deviation) as a Function of Age Group, Task Version, Congruity, and Stimulus Onset Asynchrony (SOA)

	Cue-target SOA									
	100		150		200		250		300	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Color-block task									
Older adults										
Congruent	3.19	0.18	2.22	0.20	5.42	0.52	4.86	0.20	4.86	0.46
Incongruent	3.89	0.21	4.02	0.30	4.86	0.37	4.17	0.39	5.83	0.42
Younger adults										
Congruent	1.82	0.13	2.08	0.21	1.57	0.13	1.69	0.00	1.30	0.12
Incongruent	4.55	0.27	3.26	0.26	4.03	0.17	3.26	0.20	2.60	0.12
	Color-word task									
Older adults										
Congruent	2.64	0.13	1.94	0.16	3.48	0.35	2.78	0.13	2.78	0.21
Incongruent	3.48	0.34	3.48	0.18	4.02	0.21	3.89	0.28	4.02	0.39
Younger adults										
Congruent	1.04	0.07	1.30	0.14	.52	0.12	.91	0.00	1.82	0.13
Incongruent	2.34	0.17	4.30	0.32	5.07	0.21	6.25	0.37	4.82	0.24

because both endogenous and exogenous cues would be handled by the posterior attention system, no age differences would be expected. The finding is also consistent with results obtained by Hartley et al. (1990).

The principal reason for providing the advance cue was to assure that attention was shifted to the location of the color stimulus. The SOA between the cue and target was varied to confirm that the manipulation was effective. A significant time-course effect was found for color words, indicating that there were changes in response to the cue. Although the effect was not significant for color blocks, the pattern was very similar to that for color words. It is likely that there was also a shift of attention in the color-block condition. Contrary to what might have been predicted from theories of generalized slowing, the time course for the emergence of the Stroop effects did not differ for younger and older adults; the effects of SOA were the same for the two age groups. As in the case of the cue type (exogenous or endogenous), these results are consistent with earlier findings suggesting that the deployment of spatial attention is comparable in younger and older adults (Hartley et al., 1990, 1992; Hartley & McKenzie, 1991).

It may appear that the age similarity in the color-block task and the age difference in the color-word task can be explained by age differences in the processing of extrafoveal stimuli (cf. Cerella, 1985a; Scialfa & Kline, 1988; Scialfa, Kline, & Lyman, 1987; Sekuler & Ball, 1986). The word in the color-block task was presented eccentric to fixation, and the ability to identify a target in a multi-element display drops more rapidly with eccentricity for older than for younger adults. Thus, older adults simply may have been less able to process the word perceptually, and that would have reduced the interference from the word in the color-naming task. The problem with this explanation is that the eccentricity of the words in the color-block and color-word versions was very similar. Older adults should have experienced the same reduction in interference in the color-word task as in the color-block task.

Cognitive Neuroscience of Aging and Attention

The behavioral results are consistent with the initial physiological speculation about the cognitive neuroscience of aging: Posterior brain attention systems appear, in this instance, to be unaffected by aging; anterior brain attention systems appear to be compromised. This developmental dissociation invites speculation about the possible role of the frontal cortex in age differences in attention.

Patients with frontal lobe dysfunction show impaired performance on the Stroop task (Perret, 1974), the Wisconsin Card Sorting Test (Drewe, 1974; Milner, 1963), the Tower of Hanoi (Shallice, 1982), and Block Design (Lhermitte, Derouesne, & Signoret, 1972) and Picture Arrangement subscales from the Wechsler Adult Intelligence Scale (McFie & Thompson, 1972). In general, the more direction, organization, monitoring, and correction a task demands, the more it will be affected by frontal lobe damage (Stuss & Benson, 1984). Older adults also do less well than younger adults do on many of the same tasks that are sensitive to frontal damage (e.g., Charness, 1987; Salthouse, 1991; Tecce, Yrchik, Meinbresse, Dessonville, & Cole, 1980).

It would be premature to conclude, because older adults show impaired performance on many of the same tasks as patients with frontal lobe damage, that age differences in cognitive performance are due to frontal lobe dysfunction. The similarities do, however, suggest this as a hypothesis for future research. It has been proposed that the principal function of the prefrontal cortex (that portion of the frontal lobes rostral to the motor and premotor cortex) is the organization and execution of complex, temporally organized processing sequences (Fuster, 1980; Kolb & Whishaw, 1990). This function is supported by three subordinate functions: (a) anticipating and then acquiring relevant information for guiding processing, (b) holding the relevant information "on-line" for the temporally extended period over which processing is performed, and (c) suppressing interfering or competing lines of processing. Specifically, Goldman-Rakic (1987; Goldman-Rakic, Funahashi, & Bruce, 1990) has presented electrophysiological evidence that prefrontal cortex plays an important role in working memory, the memory that briefly holds information pertinent to ongoing processing. Relevant to these functions, older adults do report lapses of attention in which they lose an ongoing action plan or fail to notice or retain information relevant to the successful execution of the plan (e.g., Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988). Moreover, there is considerable evidence for impaired working memory in older adults (e.g., Salthouse, 1991). In some circumstances, they are more distracted by irrelevant information (e.g., visual search, Fisk & Rogers, 1991); in other circumstances, they may perseverate on an action plan when it should be abandoned (e.g., Tecce et al., 1980). The most interesting point, however, concerns claims that attentional capacity may be lower in older adults (e.g., Madden, 1990a; Madden & Plude, 1993). These claims derive largely from noticeably poorer performance by older than younger adults when more than one task must be carried out at the same time. The kind of "contention scheduling" necessary to carry out multiple action plans is selectively affected by anterior brain pathology (Shallice, 1982). The analogy of changes that are due to age and changes that are due to frontal dysfunction merits exploration.

The broad implications of the present research are clear. Attention is not a unitary process. When investigators study age differences in the ability to attend, to select some thing and inhibit others, they must be very clear whether they are studying the selection of a location in space (or some other particular feature of the stimulus such as color or shape) or the selection of a line of processing. When investigators discuss the aging of attention, they must focus their attention on which attention system is doing the focusing.

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