Adult Age Differences in the Inhibition of Return of Visual Attention

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Responses to targets are slower when they appear at a location to which attention has previously been directed than when they appear at other locations. This *inhibition of return* (IOR) effect is subserved by posterior brain attentional systems. In 4 experiments the IOR effect in elderly adults was found to be at least as large as in young adults for both discrimination tasks and for detection tasks. The time course and the spread of inhibition within the visual field were also equivalent in the 2 age groups. Additive factors logic was then used to test the hypothesis that the Stroop and IOR effects are due to a common mechanism, a failure to suppress attention. This hypothesis was not confirmed. The results of the 6 experiments are consistent with the hypothesis that there are changes in posterior brain systems responsible for selective attention to a location, contrary to prior claims. They cannot be explained by a general slowing of processing in old age.

Studies of brain-damaged patients and measures of brain activity in normal adults indicate that attention is subserved by multiple systems in the human brain (see Posner & Petersen, 1990, for a review). Attention to a spatial location involves posterior brain structures. The disengagement and shift of attention appear to be controlled by parietal cortex (Corbetta, Miezin, Shulman, & Petersen, 1993; Posner, Walker, Friedrich, & Rafal, 1984); focusing of attention, by the posterior thalamus (LaBerge & Buchsbaum, 1990); and both overt orienting and the covert shift of attention by midbrain structures, including the superior colliculi (Posner, Rafal, Choate, & Vaughan, 1985). Selection for action, that is, attention to one of several possible lines of processing, or the maintenance of attention on the location or identity of an object involves frontal brain structures such as anterior cingulate and prefrontal cortex (Corbetta et al., 1993; Goldman-Rakic, 1987; Goldman-Rakic, Funahashi, & Bruce, 1990; Pardo, Pardo, Janer, & Raichle, 1990).

There are two major visual pathways to the cortex (Schneider, 1969). The geniculostriate pathway projects from the retina to the lateral geniculate nucleus of the thalamus and, in turn, to occipital cortex. The tectopulvinar pathway projects from the retina to the superior colliculi in the tectal area of the midbrain and, in turn, to the pulvinar nucleus of the dorsal thalamus and to parietal cortex. The tectopulvinar pathway is centrally involved in preparation for eye movements including both preparatory, covert shifts of attention and overt saccades (Rafal, Henik, & Smith, 1991). The functioning of this system can be seen in the phenomenon of inhibition of return. If a target is preceded by a peripheral signal at the same location, detection of the target is initially facilitated (e.g., Posner, 1980) and midbrain oculomotor centers are biased to prepare a saccade to the location (Posner & Cohen, 1980). The initial facilitation is followed by an inhibition that slows detection of the target and biases against a saccade to the location. This latter, inhibitory effect, termed *inhibition of return*, is well established (Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984; Posner et al., 1985; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987). There is converging evidence from brain-damaged patients and normal individuals that inhibition of return results from the functioning of the tectopulvinar visual pathway. Patients with peritectal degeneration resulting from progressive supranuclear palsy show deficits in inhibition of return; the deficits are not seen in control patients with lesions in other areas (Posner et al., 1985). In normal adults, Rafal, Calabresi, Brennan, and Sciolto (1989) showed with monocularly presented stimuli that inhibition of return is stronger for stimuli presented in the temporal visual hemifield than for stimuli presented in the nasal hemifield. The tectopulvinar pathway is essentially monocular, unlike the binocular geniculostriate pathway. Moreover, the nasal hemiretina has a larger direct input to the ipsilateral superior colliculus than does the temporal hemiretina, a fact that is consistent with a greater inhibition of return in the temporal hemifield.

Posner and Cohen (1984) suggested that inhibition of return may serve to make visual search more efficient because it biases against a return of attention and gaze to locations that have already been scanned. Age-related differences in inhibition of return have not been explored. Because the rate of visual search is reliably slower in older adults than in younger adults (for recent reviews, see Hartley, 1992; Madden, 1990a; Madden & Plude, 1993; McDowd & Birren, 1990), inhibition of return may make an important contribution to explaining age-related differences in attentional functioning. If inhibition of return is impaired in older adults, previously visited locations would be more likely to be re-

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visited and, as a result, search would be less efficient and slower in older than in younger adults.

Hartley (1993) has proposed that age-related differences in attentional performance will be found primarily in tasks subserved by anterior brain attentional systems; tasks subserved by posterior brain systems will show relatively small age-related differences. We tested the second part of that proposal in the present experiments. Because inhibition of return results from the operation of posterior brain attention systems concerned with spatial location, the phenomenon should not be weakened in older adults according to this proposal.

Experiment 1

Our goal in the first experiment was to establish the nature of the inhibition of return effect in older adults. We modeled the procedure very closely on that of Rafal et al. (1989). It is shown schematically in Figure 1. On each trial three boxes were presented; one was central (at fixation), and the other two were peripheral. A target appeared at some point in one of the boxes. On half of the trials, a halo appeared around one of the peripheral boxes and the target then appeared in one of those boxes. On 80% of these trials (40% of all trials), the target appeared in the box around which the halo had appeared. Thus the halo served with high validity as a cue to the target location. Following Rafal et al. (1989), we call these trials *single-cue trials*. On the other half of the trials, called *double-cue trials,* a halo appeared around one of the peripheral boxes. That halo was then removed and a halo appeared around the center box. The target was then equally likely to appear in either of the peripheral boxes. Because attention was presumed to have been shifted to the peripheral box that had first had the halo

and then shifted back to the central box, we expected reaction times (RTs) to a target appearing in that peripheral box to be longer than those to a target appearing in the peripheral box that had not been previously attended. That is, there should be an inhibition against returning to a previously visited location that should slow responses to targets appearing there. We included the single-cue trials to increase the likelihood that attention would be shifted to the peripheral location (although the sudden brightening might have been sufficient to accomplish that; see Yantis & Jonides, 1984, 1990). The results from the single-cue trials could also be compared to findings from previous research showing that the effects of valid versus invalid cues in older adults are the same as or larger than those in younger adults (Greenwood, Parasuraman, & Haxby, 1993; Hartley, Kieley, & Slabach, 1990; Nissen & Corkin, 1985). For the double-cue trials, the prediction from the theory that posterior attention systems are relatively spared in old age was that the inhibition of return effect, the difference in RT between targets appearing in the peripheral box ipsilateral to the cue and those appearing in the box contralateral to the cue, would be equivalent in younger and older adults. Following Rafal et al. (1989), we varied the stimulus onset asynchrony (SOA) on both single-cue and double-cue trials. For single-cue trials, this was the delay between the peripheral cue and the target. For double-cue trials, this was the delay between the central cue and the target. In this way we could compare the time course of the cuing and inhibition of return effects for younger and older adults.

Method

Participants. Seventeen older and 17 younger adults participated in Experiment 1. The older adults were 3 men and 14 women who were
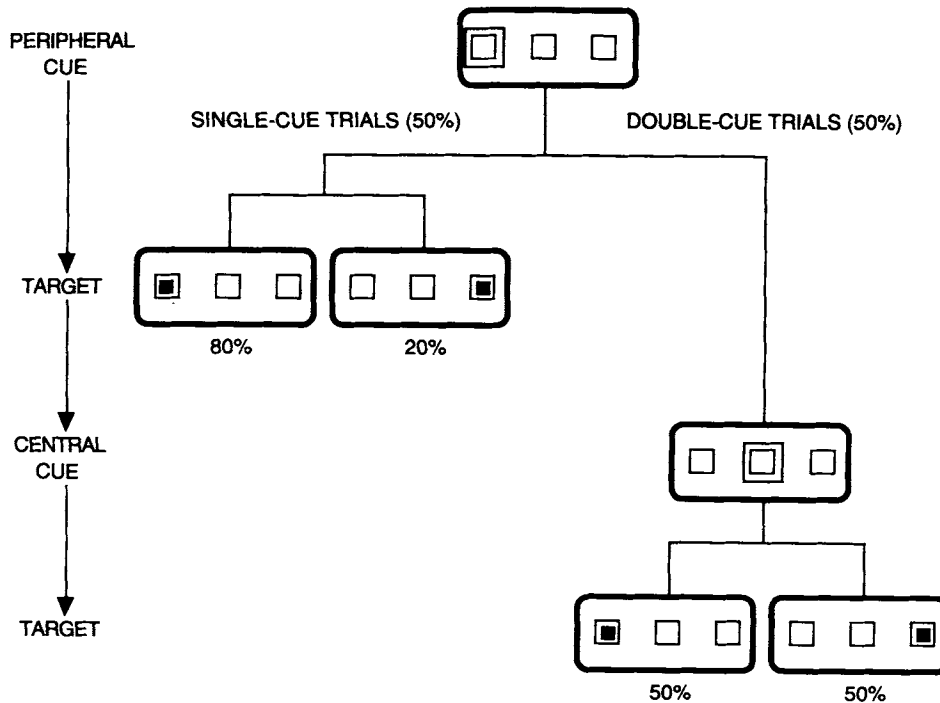

Figure 1. Sequences of events in Experiment 1.

volunteers from the local community. Their average age was 71.9 years (range = 64–81). The younger adults were 5 men and 12 women who were recruited from the undergraduate student population at the Claremont Colleges. Their average age was 20.9 years (range = 19–22). The groups did not differ significantly in number of years of education (M = 14.5 years for younger adults; M = 14.3 years for older adults), $t(32)$ = 0.26, ns, or in self-rated health assessed with a 10-point scale on which 10 was *excellent* (M = 7.8 for younger adults; M = 7.7 for older adults), $t(32)$ = 0.18, ns. Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 37 cm (14.5 in.). Median acuity was 20/20 for the younger adults and 20/30 for the older adults. The worst cases were 20/30 for 2 of the younger adults and 20/40 for 5 of the older adults. (An acuity of 20/100 would have been more than sufficient to discriminate the target stimuli.)

Displays. Instructions and stimuli were presented and responses collected with an Apple Macintosh Plus computer; the video screen was 18.8 cm wide and 14.2 cm high. The participant was seated so that the eyes were approximately 46 cm from the screen, although head position was not constrained. The methods used closely follow those of Rafal et al. (1989). All displays were in white on a black background. Each trial began with a fixation cross presented at the center of the screen for 500 ms. The screen was then cleared and remained blank for a randomly determined interval of 500 to 1,500 ms. Three square boxes, each 1° by 1°, were then presented. The boxes were centered on the horizontal midline of the screen. The central box was at the center of the screen; the two peripheral boxes were centered 4° to the left and right of the center. On each trial, one of the two peripheral boxes was surrounded by a halo. The halo was removed after 300 ms. On single-cue trials, the next event was the presentation of the target, a filled white square subtending 0.25° on a side, in one of the two peripheral boxes. On half of the cued trials, the target appeared 150 ms after the onset of the boxes (that is, 150 ms before the offset of the halo cue). On the remaining half of the cued trials, the target appeared 350 ms after the onset of the boxes (that is, 50 ms after the offset of the halo cue). The target was removed and the screen cleared after 200 ms. An additional 1,300 ms were allowed for the participant to respond. On double-cue trials, the next event after the removal of the halo cue was the presentation of a second halo around the center box. This halo remained visible for 300 ms and was then removed. After a delay of either 150 ms or 450 ms (an SOA of 450 or 750 ms from the onset of the center halo), the target was presented in one of the two peripheral boxes. As in the single-cue trials, it remained visible for 200 ms, after which the screen was cleared and an additional 1,300 ms were allowed for a response. There was an interval of 500 to 1,500 ms, randomly determined, between trials.

Procedure. There were three, 80-trial blocks preceded by a 40-trial practice block (from which the data were discarded). Each block comprised half single-cue trials and half double-cue trials, randomly ordered. The participant was allowed to rest after each block. On the single-cue trials, the halo cue was valid on 80% of the trials and invalid on the remaining 20%. On the double-cue trials the target was equally likely to appear in either of the peripheral boxes. The participants were instructed that the task was to press the space bar on the computer keyboard whenever a small square appeared in either of the peripheral boxes. They were further instructed to respond as quickly as possible but without making errors. It was explained that on some trials the target would immediately follow the first halo cue, whereas on other trials there would be a second halo cue before the target appeared. The participant was asked to keep his or her gaze fixed on the center box throughout the trial.

Results

The dependent variables were the RT to the onset of the target and the proportion of trials on which errors occurred. In order

to minimize the effects of anticipatory responses, we discarded RTs less than 200 ms. In all of the experiments reported here, these were treated as error trials.

Single-cue trials. An analysis of variance was carried out on the RTs on single-cue trials, with age group as a between-subjects factor and cue validity (valid and invalid) and cue–target SOA (150 and 350 ms) as within-subjects factors. The mean RTs are shown in Figure 2. There were significant main effects of age, $F(1, 32)$ = 16.97, $p < .001$, MSE = 7,854.36; cue validity, $F(1, 32)$ = 55.28, $p < .001$, MSE = 808.26; and SOA, $F(1, 32)$ = 6.05, $p < .05$, MSE = 678.36. Older adults (M = 450 ms, SD = 58 ms) were slower than younger adults (M = 388 ms, SD = 39 ms). RTs were shorter with a 150-ms SOA (M = 414 ms, SD = 50 ms) than with a 350-ms SOA (M = 425 ms, SD = 47 ms), and they were shorter on validly cued trials (M = 401 ms, SD = 44 ms) than on invalidly cued trials (M = 437 ms, SD = 53 ms). There were significant two-way interactions of age group and cue validity, $F(1, 32)$ = 21.72, $p < .001$, MSE = 808.26, and of age group and SOA, $F(1, 32)$ = 7.67, $p < .01$, MSE = 678.36. The cue validity effect, the difference in RTs between validly and invalidly cued RTs, was larger for older adults (M = 59 ms) than for younger adults (M = 14 ms). Younger adults were, on average, 24 ms faster with a 150-ms SOA than with a 350-ms SOA; older adults did not differ in the two conditions. There was also a significant three-way interaction of age group, cue validity, and SOA, $F(1, 32)$ = 4.64, $p < .05$, MSE = 704.62. As can be seen in Figure 2, the cue validity effect was the same at 150- and 350-ms SOAs for younger adults, whereas the cue validity effect was larger at the 350-ms SOA than the 150-ms SOA for older adults. An analysis of variance on the proportion of errors produced no significant effects. The overall average was .024 (younger adults, M = .015, SD = .041; older adults, M = .033, SD = .047).

Double-cue trials. An analysis of variance was carried out on the RTs on double-cue trials, with age group as a between-
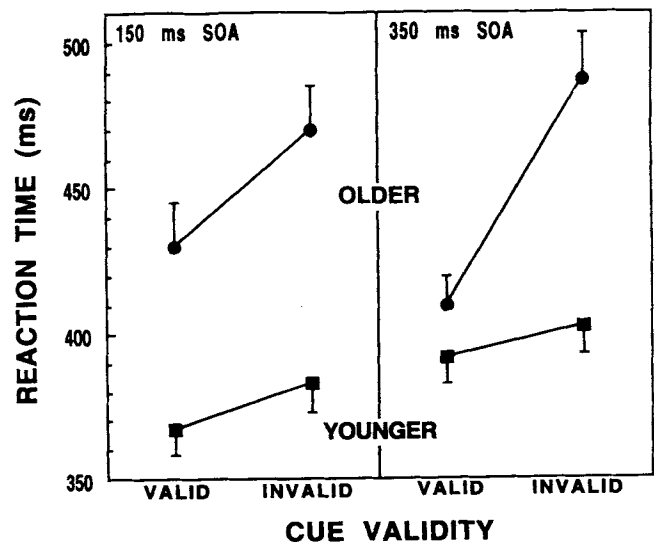

Figure 2. Mean reaction times (in milliseconds) on single-cue trials in Experiment 1 as a function of age group, cue validity, and stimulus onset asynchrony (SOA). Bars show standard error.

subjects factor and center-cue-to-target SOA (450 and 750 ms) and side of target (ipsilateral to the first halo cue—the location at which inhibition of return would be expected—and contralateral to the first halo cue) as within-subjects factors. The mean RTs are shown in Figure 3. There were significant main effects of age, $F(1, 32) = 31.94$, $p < .001$, $MSE = 7,228.09$; SOA, $F(1, 32) = 42.42$, $p < .001$, $MSE = 494.51$; and target side, $F(1, 32) = 103.32$, $p < .001$, $MSE = 669.45$. Again, older adults ($M = 438$ ms, $SD = 52$ ms) were slower than younger adults ($M = 356$ ms, $SD = 39$ ms). RTs were longer with a 450-ms SOA ($M = 409$ ms, $SD = 49$ ms) than with a 750-ms SOA ($M = 384$ ms, $SD = 42$ ms), and they were longer when the target appeared in the box that had the first halo cue ($M = 419$ ms, $SD = 48$ ms) than when it appeared in the box that had not had the first halo cue ($M = 374$ ms, $SD = 44$ ms). The only other significant effect was an interaction of SOA and target side, $F(1, 32) = 8.62$, $p < .01$, $MSE = 219.29$. The difference in RTs between targets presented on the same and different sides was larger with a 450-ms SOA ($M = 53$ ms) than with a 750-ms SOA ($M = 37$ ms). The interaction of age group and target side was not significant, $F(1, 32) = 1.46$, ns, $MSE = 669.45$; the average difference between target sides, the inhibition of return effect, was 50 ms for older adults and 40 ms for younger adults. An analysis of variance on the proportion of errors produced no significant effects. The overall average was .023 (younger adults, $M = .016$, $SD = .036$; older adults, $M = .030$, $SD = .049$).

Discussion

The results replicated the frequently obtained finding that older adults are slower than younger adults (for reviews, see Cerella, 1985, 1991; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1991). The results from the cued trials also replicated findings that older adults benefit at least as much from advance cues as do younger adults (Greenwood et al., 1993; Hartley et al., 1990; Nissen & Corkin, 1985). The cue validity effects also increased with increasing SOA for older adults but not for younger adults. This is consistent with the finding in some investigations that the effects of cues take longer to develop in older adults (Hoyer & Familant, 1987; Madden, 1990b). Other investigations have found no age differences in the time course of cue effects (Hartley et al., 1990; Madden, 1986).

The important results concern inhibition of return. The earlier finding by Rafal et al. (1989) was replicated: RTs were slower to targets appearing at a location to which attention had previously been directed than to targets appearing at a location to which attention had not been directed. Thus responses to the same location can be either facilitated or inhibited depending on whether attention remains at the location, as in the single-cue trials, or has been shifted to another location, as in the double-cue trials (where attention is shifted to the central box). Most important, the inhibition of return effect did not differ between younger and older adults. Not only was the difference nonsignificant, the mean effect was larger for older adults than for younger adults. The explanation for the reduction in the inhibition of return effect with increasing SOA is not clear. Rafal et al. (1989) found no change with SOA, and Posner and Cohen (1984) showed the effect lasted at least 1,500 to 2,000 ms. Nonetheless, the change in inhibition of return with SOA did
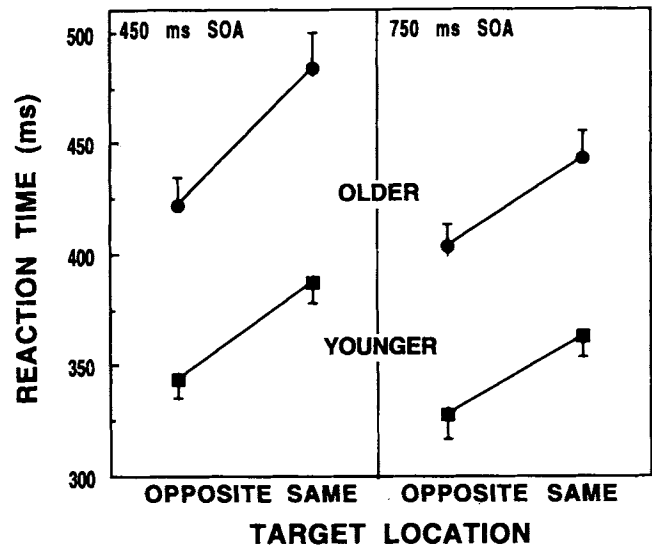

Figure 3. Mean reaction times (in milliseconds) on double-cue trials in Experiment 1 as a function of age group, target side (ipsilateral or contralateral to the first cue), and stimulus onset asynchrony (SOA). Bars show standard error.

not interact with age, so this finding does not qualify the conclusion that inhibition of return operates in a similar fashion in younger and older adults.

The times between events on a trial were such that saccadic eye movements could have been made to cued locations. The age similarities might then be some artifact of different eye movement strategies in the two age groups. Rafal et al. (1989), however, found that the inhibition of return effect was independent of whether or not eye movements were made. Thus it is unlikely that the present results can be attributed to eye movements.

Experiment 2

In Experiment 1 we replicated the well-established finding that the detection of a target is affected by inhibition of return. We conducted Experiment 2 to determine whether inhibition of return also affects discrimination. Terry, Valdes, and Neill (1994) obtained inhibition of return in a detection task but not in a discrimination task. Both their detection and discrimination tasks, however, used a rather different procedure from that used in Experiment 1: On each trial a target appeared to the left or right of fixation and was responded to. Inhibition of return to a location would have to occur across trials. In the procedure used in Experiment 1 (and also by Posner & Cohen, 1984, and Rafal et al., 1989), attention was directed to a location, directed away, and then directed back again, all within the same trial. Although it is not clear why this procedural difference should be important, the procedure for Experiment 2 was closely modeled on that of Experiment 1 except that target discrimination was required.

Method

Participants. Twenty older and 20 younger adults participated in Experiment 2. The older adults were 7 men and 13 women who were

volunteers from the local community. Their average age was 76.0 years (range = 62–88). The younger adults were 7 men and 13 women who were recruited from the undergraduate student population at the Claremont Colleges. Their average age was 20.4 years (range = 18–23). The participants did not differ significantly in number of years of education (M = 13.5 years for younger adults; M = 13.8 years for older adults), $t(38)$ = 0.24, ns, or in self-rated health assessed with a 10-point scale on which 10 was *excellent* (M = 7.9 for younger adults; M = 8.2 for older adults), $t(38)$ = 0.38, ns. Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 37 cm (14.5 in.). Median acuity was 20/20 for the younger adults and 20/30 for the older adults.

Displays. Instructions and stimuli were presented and responses collected with an Intel 486-based microcomputer with an SVGA monitor; the display area on the video screen was 24.3 cm wide and 19.0 cm high. The participant was seated so that the eyes were approximately 46 cm from the screen, although head position was not constrained. All displays were on a black background (except that instructions and messages to the participant appeared in white on a blue background). Each trial began with the presentation of three gray, outline boxes, each 2.5° square. The boxes were centered on the horizontal midline of the screen. The central box was at the center of the screen; the two peripheral boxes were centered 6.8° to the left and right of the center. After 500 ms, the color of one of the two peripheral boxes was brightened from gray to white. The box was dimmed again to gray after 300 ms. On single-cue trials, the next event was the presentation of the target 50 ms later in one of the two peripheral boxes. The target was either the letter C or the letter O, displayed in white and subtending 1.4° × 1.9°. The target was removed and the screen cleared after 200 ms. An additional 1,300 ms were allowed for the participant to respond. On double-cue trials the next event after the dimming of the peripheral box was the brightening of the center box. The center box remained brightened for 300 ms and was then dimmed. After a delay of 450 ms the target was presented in one of the two peripheral boxes. As in the single-cue trials, it remained visible for 200 ms, after which the screen was cleared and an additional 1,300 ms were allowed for a response. There was an interval of 1,000 ms between trials.

Procedure. There were three, 58-trial blocks preceded by a 40-trial practice block (from which the data were discarded). Each block comprised 30 single-cue trials and 28-double cue trials, randomly ordered. The participant was allowed to rest after each block. As in Experiment 1, on the single-cue trials, the brightening cue was valid on 80% of the trials and invalid on the remaining 20%. The participants were instructed that the task was to press the corresponding key on the computer keyboard whenever a letter appeared in either of the peripheral boxes. For half of the participants, C was assigned to the . (period) key and O to the / (forward slash) key; for the other half, the assignments were reversed. Participants were further instructed to respond as quickly as possible but without making errors. It was explained that on some trials the target would immediately follow the first brightening cue, whereas on other trials there would be a second brightening cue before the target appeared. The participant was asked to keep his or her gaze fixed on the center box throughout the trial and was monitored during practice to ensure that the instruction was followed.

Results

The dependent variables were the RT to the onset of the target and the proportion of trials on which errors occurred. In order to minimize the effects of anticipatory responses, we again discarded RTs less than 200 ms.

Single-cue trials. An analysis of variance was carried out on the RTs on cued trials, with age group as a between-subjects factor and cue validity (valid and invalid) as a within-subjects

factor. There were significant main effects of age, $F(1, 38)$ = 28.47, $p < .001$, MSE = 29,264.37, and cue validity, $F(1, 38)$ = 62.73, $p < .001$, MSE = 2,777.21. Older adults (M = 699, SD = 123 ms) were slower than younger adults (M = 554 ms, SD = 63 ms). RTs were shorter on validly cued trials (M = 594 ms, SD = 84 ms) than on invalidly cued trials (M = 660 ms, SD = 102 ms). The cue validity effect, the difference in RTs between validly and invalidly cued targets, did not differ between older adults and younger adults, $F(1, 38)$ = 0.10, ns, MSE = 2,777.21: For older adults mean RTs were 665 ms (SD = 117 ms) and 733 ms (SD = 130 ms) to validly and invalidly cued targets, respectively, for a mean difference of 68 ms; for younger adults the mean RTs were 523 ms (SD = 52 ms) and 586 ms (SD = 74 ms), for a mean difference of 63 ms. An analysis of variance on the proportion of errors produced no significant effects. The overall average was .062 (younger adults, M = .052, SD = .050; older adults, M = .073, SD = .050).

Double-cue trials. An analysis of variance was carried out on the RTs on inhibition trials, with age group as a between-subjects factor and side of target (ipsilateral to the first-brightened box and contralateral to the first-brightened box) as a within-subjects factor. There were significant main effects of age, $F(1, 38)$ = 31.83, $p < .001$, MSE = 21,915.06, and target side, $F(1, 38)$ = 18.44, $p < .001$, MSE = 1,984.42. Again, older adults (M = 670 ms, SD = 132 ms) were slower than younger adults (M = 538 ms, SD = 66 ms). RTs were longer when the target appeared in the box that had first brightened (M = 620 ms, SD = 103 ms) than when it appeared in the box that had not brightened (M = 590 ms, SD = 95 ms). The interaction of age group and target side, the inhibition of return effect, did not reach significance, $F(1, 38)$ = 3.43, p = .07, MSE = 1,984.42; the average difference between sides was 43 ms for older adults (692 ms and 649 ms on the brightened and unbrightened sides, respectively; SDs = 140 ms and 124 ms, respectively) and 17 ms for younger adults (547 ms and 530 ms; SDs = 66 ms and 66 ms, respectively). An analysis of variance on the proportion of errors produced no significant effects. The overall average was .040 (younger adults, M = .032, SD = .054; older adults, M = .048, SD = .051).

Discussion

As in Experiment 1, older adults were slower than younger adults and older adults benefited at least as much from advance cues as younger adults. And, also as in Experiment 1, the important results concern inhibition of return. The finding of inhibition of return was replicated and extended to discrimination tasks. It seems likely that Terry et al.'s (1994) failure to find inhibition of return in a discrimination task was the result of their requiring a response to each attended location.

The most important finding in Experiment 2 was that the inhibition of return effect did not differ between younger and older adults. Not only was the difference nonsignificant, but once again the mean effect was larger for older adults than for younger adults.

Experiment 3

In Experiments 1 and 2 we intended the cues to induce shifts of attention to the different cued locations. Nonetheless, partic-

ipants could carry out the task without shifting attention until the target appeared. In Experiment 3 we modified the procedures so that it was necessary for participants to process information from each location in order to respond correctly; thus we made it almost obligatory that attention be shifted. As in Experiments 1 and 2, three outline boxes were presented. First, a colored square appeared in one of the peripheral boxes. Next a colored square appeared in the center box. Finally, a colored square appeared in one of the peripheral boxes. The participant's task was to say the color of the small squares if all three were the same color and to give no response otherwise. This procedure made it necessary for the participant to shift attention to one of the peripheral boxes and then shift it back to the center in order to determine whether the third small square was consistent with the colors of the two preceding squares. Because the third colored square could appear either where the first square had been or contralaterally, it was either in a location to which attention had previously been shifted, and which should therefore be inhibited, or in a location that had not been visited, and which should therefore not be inhibited. Thus the task required discrimination as in Experiment 2, although of colors rather than letters. One additional change was that the identification of the color was made by a vocal response rather than a keypress.

Method

Participants. The older adults comprised 13 women and 4 men with an average age of 75.0 years (range = 68–86); the younger adults comprised 14 women and 3 men with an average age of 22.1 years (range = 20–29). Both groups were drawn from the same populations as in the preceding experiments. The two groups did not differ in years of education (M = 14.9 years for the younger group; M = 13.8 years for the older group), $t(32)$ = 1.32, ns. They also did not differ in self-rated health (M = 8.4 for the younger group; M = 8.5 for the older group), $t(32)$ = 0.16, ns. Median visual acuity was 20/20 for the younger adults and 20/30 for the older adults. All participants were screened for defective color vision using the Dvorine plates; none were rejected for this reason.

Display and procedure. Stimuli were presented on a high-resolution, 32-cm, Apple color monitor controlled by a Macintosh IIcx computer. Voice responses were sensed and conveyed to the computer with a system described by Kieley (1991). Voice responses were made into a microphone (Shure SM-58) attached via a line matching transformer (Shure A95F) to a voice-operated relay (Lafayette Instruments). The output of the voice-operated relay was routed through a MIDI keyboard (Casio MT-240) to a MIDI interface (Opcode Professional) and, in turn, to the modem port of the computer. A library of software routines (MIDI-Basic, Altech Systems) was used to implement millisecond-accuracy timing. Voice responses were also tape-recorded for later accuracy scoring. Viewing distance was approximately 46 cm, although head position was not constrained.

Each trial began with the presentation of three boxes, outlined in white on a black background, which remained present throughout the trial. The center box, a square subtending 1.0° on a side, appeared at the center of the display. Two peripheral boxes, each subtending 2.7° horizontally and 1.0° vertically, appeared on the horizontal midline to the left and right of the center box. The centers of the peripheral boxes were 5.2° from the center of the display. A small colored square, 0.45° on a side, appeared in one of the peripheral boxes. The square was either red, blue, or green. After 300 ms, the square was removed. Then, 200 ms later, a small colored square of the same size as the first appeared in the center box. After 300 ms, that square was removed. Finally, after a

375-ms delay (an SOA of 675 ms from the onset of the colored square in the center box), a third colored square, again of the same size, appeared in one of the two peripheral boxes. The participant's task was to say the name of the color if all three small squares had been the same color and to give no response if they were not the same.

Timing was started when the third colored square was presented and stopped when the voice response was sensed. A block of 20 practice trials preceded a block of 60 experimental trials. Forty percent of the practice trials and 20% of the experimental trials had different colors and did not require a response. The square that differed in color was equally likely to be the first, second, or third. Response and no-response trials were randomly intermixed. Rest breaks were given after the practice and after 30 experimental trials.

Results

An analysis of variance was carried out on the mean correct RTs, with age group as a between-subjects factor and side of the third colored square (ipsilateral to the first square and contralateral) as a within-subjects factor. Although older adults were slower (M = 621 ms, SD = 85 ms) than younger adults (M = 582 ms, SD = 104 ms), the difference was not significant, $F(1, 32)$ = 1.65, ns, MSE = 31,918.50. There was a significant main effect of target side, $F(1, 32)$ = 35.51, $p < .001$, MSE = 1,403.78. RTs when the third colored square was on the same side as the first, the presumably inhibited location, were longer (M = 622 ms, SD = 100 ms) than RTs when the two squares were on different sides (M = 583 ms, SD = 88 ms). There was a significant interaction of age group and target side, $F(1, 32)$ = 6.91, $p < .05$, MSE = 1,403.78. The inhibition of return effect was significantly larger for older adults (M = 55 ms) than for younger adults (M = 21 ms). An analysis of variance on the proportion of errors produced no significant effects. The overall average was .024 (younger adults, M = .016, SD = .048; older adults, M = .032, SD = .082).

Discussion

The results of Experiment 3 showed several things. First, inhibition of return also occurs when information must be processed at an attended peripheral location. Second, the finding that inhibition of return occurs with discrimination as well as detection was replicated and extended to the identification of colors as well as letters. Third, inhibition of return can be obtained with vocal as well as manual responses. Fourth, and most important, inhibition of return was greater in older adults than younger adults as in Experiments 1 and 2; in Experiment 3, however, the difference was significant.

Experiment 4

The inhibitory effect of a cue preceding the target is not confined to the location of the cue (Berlucchi et al., 1989; Tassinari et al., 1987). Inhibition has been found for locations separated from the cue by as much as 20°, although the inhibitory effect does not appear to cross the vertical midline (or the horizontal midline for vertically arrayed stimuli). It is possible, then, that inhibition of return is indeed reduced in older adults, although this was not seen in the preceding experiments. The argument is as follows: Although the effect at the location of the cue may show no age-related difference, the spread of inhibition in older

adults could be less, resulting in reduced inhibition of return at other locations in the cued hemifield for older adults relative to younger adults. We explored this possibility in Experiment 4.

The display was fundamentally the same as in Experiment 3 except that four more peripheral boxes were added, two in the same field as the first cue and two in the opposite field, which resulted in six locations in which the final target could appear. This is shown schematically in Figure 4. As in Experiment 3, we attempted to ensure that attention was shifted. On each trial, a small target square appeared in one of the two peripheral boxes along the midline. After a delay, that target square was erased. Next, a square appeared in the central box and, after a delay, was erased. Finally a square appeared in one of the six peripheral boxes. Each of the three small squares could either be filled or empty. The participant's task was to respond only if all three small squares had been filled. Thus participants had to attend to each of the three locations in order to discriminate whether or not the small square was filled. Because the third square could appear (a) at the same location as the first square, (b) in the same hemifield as the first square but not at the same location, or (c) in the hemifield opposite to the first square, it was possible for us to determine whether inhibitory effects would be seen at locations other than that of the first square.

If the spread of inhibition is impaired in older adults, then the results should show (a) that RTs are slowed when the third square appears in the same hemifield as the first square, although less than when the third square appears at exactly the same location as the first square, and (b) that the slowing in the same hemifield should be less in older adults than younger adults.

Method

Participants. There were 16 older adults (4 men and 12 women) with an average age of 75.5 years (range = 67–86) and 16 younger adults (3 men and 13 women) with an average age of 18.8 years (range = 18–21). They were recruited from the same populations as those in previous experiments. The older adults averaged 14.2 years of education; the younger adults averaged 12.7 years. This difference was not significant, $t(30) = 1.86$, ns. Self-rated health averaged 8.3 for the older adults and 7.7 for the younger adults; this difference was not significant, $t(30) = 0.88$, ns. Median acuity was 20/20 in the younger group and 20/30 in the older group.

Display and procedure. The instrumentation and displays were identical to those in Experiment 3 with the exception that four new peripheral boxes were added. All of the peripheral boxes were identical in size. The four additional boxes were placed along the positive and negative diagonals passing through the center of the display; as with the peripheral boxes lying on the horizontal midline, the center of each box was 5.2° from the center of the display. Each trial began with the presentation of the seven outline boxes, one central box and six peripheral boxes. After a variable delay, the first target, a small square 0.45° on a side, appeared in one of the two peripheral boxes lying along the horizontal midline. The square was either filled or outlined in white. After 300 ms, the first target was removed. Then, 200 ms later, the second target, a square of the same size as the first, appeared in the center box. Again, it was either filled or outlined. After 300 ms, the second target was removed. Finally, after either a 300-ms or a 450-ms delay (an SOA of 600 ms or 750 ms from the onset of the square in the center box), a third target, again a square of the same size and either filled or outlined, appeared in one of the six peripheral boxes. The participant's task was to respond by saying the word *go* if and only if all three targets had been filled and to withhold a response otherwise. There was a practice block
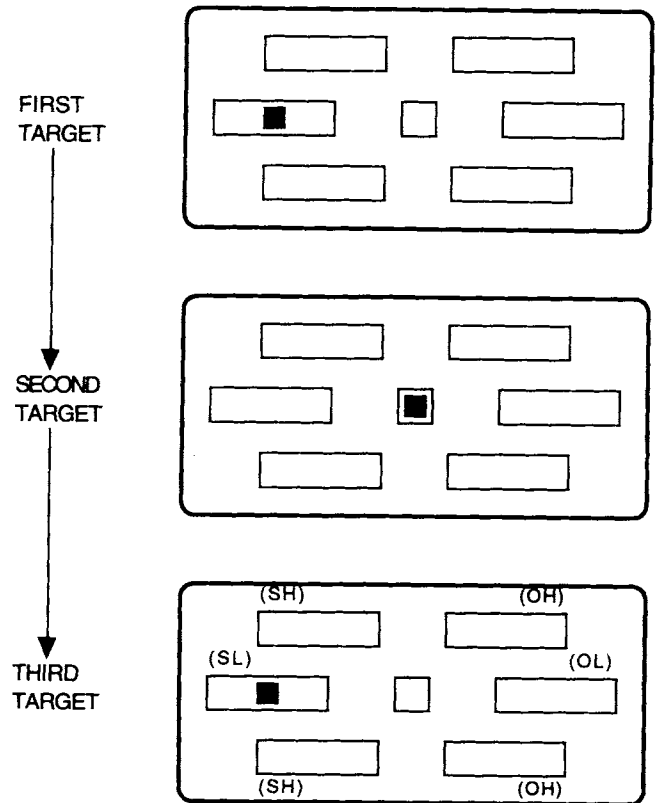

Figure 4. Sequence of events in Experiment 4. Abbreviations for the labels used in the discussion of the target locations are shown in the display for the third target (these were not shown during the experiment): SL = same location as first target, OL = opposite location, SH = same hemifield as first target, OH = opposite hemifield.

of 24 trials followed by 120 experimental trials, with rest breaks after 40 and 80 trials. Forty percent of the practice trials and 20% of the experimental trials had one of the three targets outlined rather than filled and did not require a response. On these trials, the outlined target was equally likely to be the first, second, or third target. Response and no-response trials were randomly intermixed.

Results

The dependent variables were the RT to the onset of the third target and the proportion of trials on which errors occurred. There were no RTs less than 200 ms, so no data were discarded for this reason. An analysis of variance was carried out on the RTs to the third target, with age group as a between-subjects factor and center-target-to-third-target SOA (450 and 750 ms), side of the third target (ipsilateral to the first target and contralateral to the first target), and location of the third target (along the horizontal midline and displaced above or below the midline) as within-subjects factors. A preliminary analysis showed no effect of whether the target was above rather than below the midline, so the data were collapsed across this factor. The mean RTs are shown in Figure 5.

There was a significant main effect of age group, with older adults ($M = 684$ ms, $SD = 92$ ms) being slower than younger adults ($M = 612$ ms, $SD = 102$ ms), $F(1, 30) = 5.05$, $p < .05$,
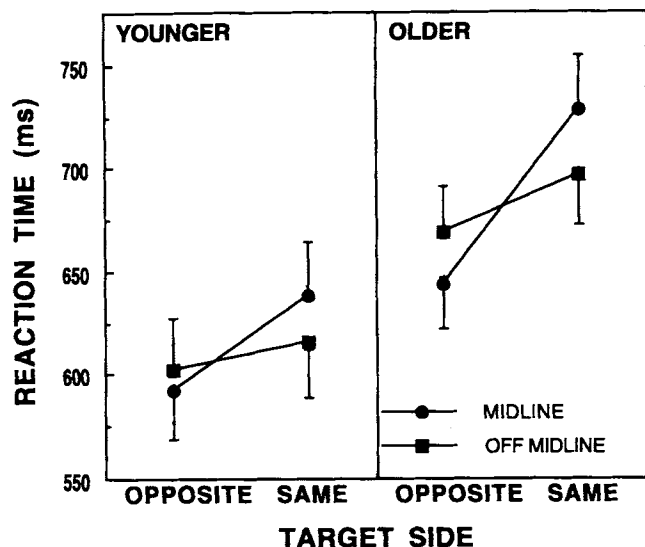
Figure 5. Mean reaction times (in milliseconds) in Experiment 4 as a function of age group, third target side (ipsilateral or contralateral to the first target), and third target location (on or off horizontal midline). Bars show standard error.

$MSE = 66,136.23$. Targets ipsilateral to the cue, in the presumably inhibited field, were responded to more slowly ($M = 670$, $SD = 104$ ms) than targets in the contralateral field ($M = 627$, $SD = 91$ ms), $F(1, 30) = 49.21$, $p < .001$, $MSE = 2,388.30$. This effect was qualified by an interaction of target side and age group, $F(1, 30) = 4.47$, $p < .05$, $MSE = 2,388.30$. The average inhibition of return effect, the difference between RTs in the ipsilateral and contralateral fields, was 55 ms for the older adults and 30 ms for the younger adults. Target side also interacted with target location, with the difference between the ipsilateral and contralateral fields being greater for targets along the midline ($M = 64$ ms) than for targets above or below the midline ($M = 22$ ms), $F(1, 30) = 17.61$, $p < .001$, $MSE = 1,659.03$. There was no three-way interaction; the nature of the interaction between target side and target location was the same for younger as for older adults, $F(1, 30) = 1.43$, ns, $MSE = 1,659.03$.

There was a significant main effect of the SOA between the center cue and the target, with RTs being longer at the 750-ms SOA than at the 450-ms SOA, $F(1, 30) = 4.32$, $p < .05$, $MSE = 2,471.52$. This effect was due entirely to the older adults, who were 28 ms slower with the longer SOA ($Ms = 670$ ms and 698 ms for the 450-ms and 750-ms SOAs, respectively; $SDs = 80$ ms and 104 ms, respectively); the younger adults did not differ ($Ms = 613$ ms and 611 ms, respectively; $SDs = 105$ ms and 99 ms, respectively). Consistent with this, the interaction of age group and SOA was significant, $F(1, 30) = 5.78$, $p < .05$, $MSE = 2,471.52$. The effect of SOA also interacted with target side, $F(1, 30) = 10.67$, $p < .001$. The inhibition of return effect was reduced from 54 ms at the shorter SOA to 32 ms at the longer SOA. The mean RTs for the ipsilateral and contralateral targets, respectively, were 669 ms ($SD = 101$ ms) and 615 ms ($SD = 84$ ms) for the 450-ms SOA and 671 ms ($SD = 107$ ms) and 639 ms ($SD = 97$ ms) for the 750-ms SOA. The three-way interaction of

SOA, target side, and age group was not significant, $F(1, 30) = 2.74$, ns, $MSE = 762.07$.

An analysis of variance on the proportion of errors produced no significant effects. The overall average was .013 (younger adults, $M = .009$, $SD = .018$; older adults, $M = .017$, $SD = .031$).

Discussion

The results of Experiment 4 replicate the inhibition of return effect and again show that it affects discrimination as well as detection. The inhibitory effect was significantly greater for older adults than for younger adults, as in Experiment 3. In addition to the inhibitory effect at the location of the first cue, inhibition was also found at other locations in the same hemifield, and the spread of the effect was the same for younger and older adults. Finally, the magnitude of the inhibition of return effect diminished with increasing SOA as in Experiment 1, but, again, the time course was the same for younger and older adults.

For targets in the contralateral field, which should not have been affected by inhibition, RTs were longer for locations above or below the midline than for locations on the midline. This may reflect differential expectations. Although the third target was equally likely in all six peripheral locations following a second, central cue, the first and second targets always appeared along the midline. This may have increased expectation of targets along the midline. If this argument is correct, it has two implications. First, the slowing that was due to inhibition was even greater than the results indicate because it was superimposed on facilitation that was due to a target's appearing along the midline. Second, there was inhibitory slowing for targets in the ipsilateral field but off the midline (beyond any effect of occurring at an unexpected location) because RTs were longer for those locations than for analogous locations in the contralateral field.

General Discussion of Experiments 1–4

Inhibition of return is the bias against returning attention to a location at which it has recently been focused, shown here by lengthened RTs to targets appearing at the location of a preceding cue. Inhibition of return was not diminished in older adults; to the contrary, the effect was consistently larger in older than in younger adults, significantly so in Experiments 3 and 4. Moreover, the spread of the inhibitory effect to other locations ipsilateral to the cue (Experiment 3) and the time course of the dissipation of the effect (Experiments 1 and 4) were the same for younger and older adults. This evidence must be viewed with caution because the power of these designs to detect an effect (i.e., an interaction of an experimental variable with age group) defined by Cohen (1988) as *medium* ranged only from .28 to .34. Certainly there is no evidence that old age is accompanied by impaired inhibition of return. Consequently, the results are inconsistent with the argument that poorer visual search performance in older adults could be the result of an impaired inhibition of return's leading to inefficient search. At the same time, the results are also inconsistent with the hypothesis that tasks primarily engaging posterior brain attention systems will show little or no change with age. Inhibition of return is presumed to involve posterior brain systems, yet there were consistent age differences.

One possible explanation for the larger inhibition of return effects in older adults is that they are the result of general slowing. That is, if older adults are simply slowed overall relative to younger adults, then any effects of a variable on RT could be expected to be proportionately exaggerated. Even if the underlying inhibition were unaffected by aging, the apparent effect in RTs would be larger. If the differential age effect is due simply to a proportional increase in RT, then it should be possible to remove the effect by expressing the inhibition of return effect as a proportion of the overall average RT in order to obtain the relative size of the effect. We did this for each participant in each of the four experiments; the transformed scores were combined for a single, omnibus analysis. The proportional inhibition of return effect was significantly larger for older ($M = .093$, $SD = .069$) than for younger ($M = .063$, $SD = .075$) adults, $t(136) = 2.57$, $p = .01$. Thus the greater inhibition of return effects in older adults cannot be explained by general slowing; the inhibition of return effect was greater not only in RTs but also relative to the overall RT.[1]

Posterior Attention System Models for Age Differences in Inhibition of Return

At the level of a computational model (Marr, 1982), attention to a location is followed by inhibition at that location when attention is later directed elsewhere. It could be that inhibition accrues to the location itself. Alternatively, inhibition could accrue to the movement of attention to the location. The presumption is that these inhibitory processes are instantiated in the posterior attention system. If the location is inhibited, it would occur in the system responsible for the focusing of attention, including thalamic structures such as the pulvinar and reticular nuclei (Crick, 1984; LaBerge, 1990). The closing of an attentional focus or channel may be accomplished by inhibition or it may be accomplished in some other way, but a refractory inhibitory period may follow the closing. The larger inhibition of return effect observed in older adults could be due to greater inhibition. More plausibly, the inhibition may be the same as in younger adults but may dissipate more slowly. It may not have been possible to see the difference in rate in the present experiments if the time grain was too coarse. If, instead, the movement of attention is inhibited, the process would occur in the system responsible both for covert orienting and overt saccades, including the superior colliculus (Rafal et al., 1989). The shift of attention away from the first target may leave residual effects that interfere with execution of the instruction to return attention to that location. The age differences in inhibition of return could be due to greater persistence in the effects of shifting away from the first target location, which would lead to greater interference when an attempt was made to return.

Anterior Attention System Models of Age Differences in Inhibition of Return

There is an alternative to explanations of age differences in inhibition of return that are based on functioning of the posterior attention system. They could be due to anterior attention system operations. The anterior attention system involves structures such as the prefrontal cortex (PFC) and the anterior

cingulate cortex (ACC). The PFC is active in the strategic, executive control of processing (Shallice, 1988). The ACC is particularly active when stimuli arouse competing lines of processing and responding that must be suppressed (Corbetta et al., 1993; Frith, Friston, Liddle, & Frackowiak, 1991; Pardo et al., 1990; Paus, Petrides, Evans, & Meyer, 1993). Apparently the ACC acts to suppress processing and response activation for irrelevant stimuli when responses are not well learned, when there are several equally well-learned responses to a stimulus and the instructions require selection of one, or when there is a prepotent inappropriate response. When a well-learned response is required and no competing lines of processing are activated, activation is found in supplementary motor areas but not in the ACC (Paus et al., 1993).

In one possible model, attention to a location requires suppression of processing at recently attended locations. Thus attention to the second target would require suppression of attention and processing at the location of the first target. That suppression could have effects that persist when the third target appears at the same location as the first target. Inhibition of return effects would be greater in older adults if that suppression was stronger or more persistent than in younger adults. This model is very similar to the first posterior attention system model described; the difference is that this model is instantiated in the anterior attention system.

The first target summons attention to its location. A second possible model postulates that younger adults partially suppress that response, allocating some attention to other locations in which targets are likely to appear. If older adults are less able or likely to carry out this strategic suppression, then attention and processing would be more fully committed to the location of the first target. This would result, in turn, in greater inhibition accruing to that location for older adults. Although the accrual of inhibition could be due to the functioning of the posterior attention system, the partial suppression of attention to the first location by younger adults would be the result of age differences in the functioning of the anterior attention system. This model also accounts for the finding that the costs and benefits of advance cues are greater in older adults than in younger adults. This is precisely what would be expected if younger adults hedged their bets by suppressing processing at the cued location and allocated some attention elsewhere.

A Test of Anterior Attention System Involvement

If age differences in inhibition of return are the consequence of age differences in the function or utilization of the anterior attention system, then it should be possible to demonstrate this by introducing another, simultaneous task that also requires

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suppression of competing attentional responses and, specifically, one that is known to load the anterior attention system. Such a task should exacerbate the inhibition of return effect for older adults.

The Stroop (1935) color–word task provides a well-established marker for such processes. The Stroop procedure involves the strategic suppression of attention and processing. Color names are presented in colors that may be congruent with the names (e.g., *red* displayed in red) or incongruent (*red* displayed in blue). The participant's task is to identify the display color while ignoring the word. To the extent that attention to the words cannot be suppressed, congruent words will speed RTs and incongruent words will slow them. Moreover, there is good evidence that the Stroop procedure engages frontal brain structures; positron emission tomography (PET) scans show greater activation in anterior regions, in particular the ACC, during incongruent Stroop trials than during control tasks (Pardo et al., 1990). The Stroop effect—the difference between the RT with incongruent and with congruent words—is reliably found to be larger in older adults than in younger adults (Cohn, Dustman, & Bradford, 1984; Comalli, Wapner, & Werner, 1962; Eisner, 1972; Hartley, 1993; Obler & Albert, 1985; Panek, Rush, & Slade, 1984). This finding is consistent with greater suppression of a prepotent response, naming the word, in younger adults. Notice that the age differences in the Stroop effect are consistent with the second hypothesis involving the anterior attention system, partial suppression of the processing of the first target. They are inconsistent with the first hypothesis, which holds that suppression is either greater or more persistent in older adults. If suppression is greater, then the Stroop effect would be smaller in older adults. If the suppression is simply more persistent, that should have no bearing on the size of the Stroop effect.

If the inhibition of return effect and the Stroop effect both reflect the operation of a single mechanism in older adults—a reduction in the strategic suppression of attention by the anterior attention system—then it should be possible to use additive factors logic to verify this. The two effects should potentiate one another when they are combined, producing a superadditive interaction. That is, if older adults are less able to suppress processing, the Stroop effect should be greater when the stimuli appear at a location to which attention has previously been directed than when they appear at a location to which attention has not been previously directed. On the other hand, if age differences in the inhibition of return are due to differences in the posterior attention system rather than the anterior attention system, the inhibition of return effect and the Stroop effect should be completely independent. We tested these hypotheses in Experiment 6. First, however, we had to demonstrate that the Stroop effect could be obtained with a procedure that could then be combined with the inhibition of return procedure. We did this in Experiment 5.

Experiment 5

In the standard Stroop procedure only a single stimulus is presented on each trial. The inhibition of return procedure requires three successive stimuli on each trial. In Experiment 5 we modified the Stroop procedure so that three stimuli were presented on each trial and participants had to attend to each. First, one small colored square was presented, followed by a sec-

ond colored square. Finally, a color word, displayed in color, was presented. The participant's task was to name the color if both colored squares and the word were the same color and to give no response if any of the stimuli differed in color from the others.

Method

Participants. There were 16 older adults (6 men and 10 women) with an average age of 73.5 years (range = 65–82) and 16 younger adults (6 men and 10 women) with an average age of 21.8 years (range = 19–26). They were recruited from the same populations as the participants in the previous experiments. The older adults averaged 14.4 years of education; the younger adults averaged 14.6 years. This difference was not significant, $t(30) = 0.14$, *ns*. Self-rated health averaged 8.3 for the older adults and 8.8 for the younger adults; this difference was not significant, $t(30) = 1.88$, *ns*. Median visual acuity was 20/20 for the younger adults and 20/30 for the older adults. All participants were screened for defective color vision with the Dvorine plates; none were rejected for this reason.

Display and procedure. The instrumentation was identical to that in Experiments 3 and 4. Following the instructions, a white outline rectangle, subtending 2.7° horizontally by 1.0° vertically, was presented at the center of the display. It remained visible throughout each block of trials. On each trial, a small colored square, 0.45° on a side, was presented, centered within the outline rectangle. After 300 ms the square was removed. Then, after 200 ms a second colored square of the same size was presented in the same location. After 300 ms the second square was removed. Then, after 375 ms (an SOA of 675 ms from the onset of the second square), a color word was presented in color, centered in the rectangle. Each of the three stimuli could be displayed in red, blue, or green. The word was either *red, blue,* or *green.* Each letter subtended 0.36° horizontally by 0.63° vertically. The participant's task was to say the name of the color if all three stimuli were the same color and to give no response if any stimulus differed in color from the others. Timing was started when the color word was presented and stopped when a voice response was sensed. There were 24 practice trials and 120 experimental trials. Eight of the practice trials and 24 of the experimental trials had stimuli that differed in color and so did not require a response. The inconsistent color was equally likely to be the first, second, or third. Rest breaks were given after the practice and after 40 and 80 experimental trials.

Results

An analysis of variance was carried out on the mean correct RT, with age group as a between-subjects factor and congruency (color and color word congruent or incongruent) as a within-subjects factor. Anticipatory responses, those less than 200 ms, were again discarded. There was a significant main effect of age group, $F(1, 30) = 8.29$, $p < .01$, $MSE = 55,562.94$. Older adults ($M = 653$ ms, $SD = 73$ ms) were slower than younger adults ($M = 534$ ms, $SD = 88$ ms). There was also an effect of congruency, $F(1, 30) = 42.61$, $p < .001$, $MSE = 5,834.41$. There was a Stroop effect: Incongruent stimuli ($M = 638$ ms, $SD = 86$ ms) produced longer RTs than congruent stimuli ($M = 549$ ms, $SD = 75$ ms). There was a significant interaction of age group and congruency, $F(1, 30) = 6.68$, $p < .05$, $MSE = 5,834.41$. The Stroop effect was larger for older adults ($M = 123$ ms) than for younger adults ($M = 53$ ms). An analysis of variance on the proportion of errors produced a significant effect of age group, $F(1, 30) = 12.45$, $p < .01$; older adults had a higher proportion of errors ($M = .083$, $SD = .108$) than did younger adults ($M = .005$, $SD = .021$). No other effects were significant.

Discussion

The results of Experiment 5 demonstrate that the Stroop effect can be obtained when attention must be paid to two additional stimuli that precede the traditional Stroop stimulus. One might have predicted that this procedure would reduce or eliminate the Stroop effect: The response could be prepared as the two colored squares were processed; then the color word need only be checked to determine whether it was consistent with the prepared response. Alternatively, however, if the information about the colored squares was held in semantic form (the name of the color), then automatic activation of the meaning of the word might increase the facilitation or interference. The important result here was that a Stroop effect was obtained with the novel procedure and it was substantially larger for older adults than for younger adults, in agreement with previous research.

Unlike the preceding experiments that did not involve the Stroop effect, there were significant age differences in the proportion of errors. The error rates were higher in older adults, which is inconsistent with a speed–accuracy trade-off. Most important, there was no interaction between the congruency manipulation and age that would compromise the interpretation of the RTs.

Experiment 6

In Experiment 5 we demonstrated that the Stroop phenomenon could be obtained using procedures that could then be combined with those for inhibition of return into a single experiment. We used the combined procedures in Experiment 6 to explore the independence of the two phenomena. As in Experiment 5, a sequence of three stimuli, two colored squares followed by a color word, was presented. As in Experiment 3, the first colored square appeared in a peripheral box, the second colored square in a central box, and the third stimulus in a peripheral box. The third stimulus was a color word that could appear either in the peripheral box where the first colored square had been, presumably now an inhibited location, or in the box on the opposite side, presumably not an inhibited location. If the inhibition of return effect and the Stroop effect are independent, then the two effects should be additive: The Stroop effect should be the same whether the color word appears in a location that is inhibited or is not inhibited; the inhibition of return effect should be the same for congruent and incongruent words and colors. Alternatively, they would not be independent if there is a common mechanism such as reduced suppression of attention in older adults. Recall that this hypothesis predicts not only age differences in both effects but also a superadditive interaction of the two effects in older adults even if they are independent in younger adults: The Stroop effect should be larger at the inhibited location than at the location that is not inhibited.

Method

The participants in Experiment 6 also completed Experiment 5 in the same session; Experiment 5 was completed first.[2] The instrumentation was identical to that used in Experiments 3 and 4. The displays were similar to those used in Experiment 3 except that the stimuli were those used in Experiment 5 and

that the first colored square and the color word appeared in the peripheral boxes. The timing was identical to that in Experiments 3 and 5. There were 24 practice trials and 120 experimental trials. Eight of the practice trials and 24 of the experimental trials had stimuli that differed in color and so did not require a response. The inconsistent color was equally likely to be the first, second, or third. Rest breaks were given after the practice and after 40 and 80 experimental trials.

Results

An analysis of variance was carried out on the mean correct RTs, with age group as a between-subjects factor and word target side (ipsilateral to the first colored square and contralateral) and congruency (word and color congruent and incongruent) as within-subjects factors. There was a significant main effect of age group, $F(1, 30) = 8.27, p < .01, MSE = 97,200.48$. Older adults ($M = 666$ ms, $SD = 113$ ms) were slower than younger adults ($M = 554$ ms, $SD = 118$ ms). There was also an effect of target side, $F(1, 30) = 88.05, p < .001, MSE = 2,493.37$. There was an inhibition of return effect, with responses being slower when the color words appeared at the location of the first colored square ($M = 640$ ms, $SD = 120$ ms) than when they appeared at the opposite location ($M = 581$ ms, $SD = 111$ ms). The main effect of congruency was also significant, $F(1, 30) = 37.11, p < .001, MSE = 3,034.69$. There was a Stroop effect, with incongruent colors and words resulting in longer RTs ($M = 631$ ms, $SD = 128$ ms) than congruent colors and words ($M = 590$ ms, $SD = 103$ ms). There was a significant two-way interaction of age group with target side, $F(1, 30) = 5.09, p < .05, MSE = 2,493.37$. The inhibition of return effect was larger for older adults ($M = 73$ ms) than for younger adults ($M = 40$ ms). Age group also interacted with congruency, $F(1, 30) = 4.80, p < .05, MSE = 3,034.69$. The Stroop effect was also larger for older adults ($M = 67$ ms) than for younger adults ($M = 26$ ms). Finally, there was a significant three-way interaction of age group, target side, and congruency, $F(1, 30) = 4.77, p < .05, MSE = 1,300.91$. The origins of the three-way interaction can be seen in the mean RTs, which are shown in Figure 6. For older adults, but not for younger adults, the Stroop effect was smaller when the color word appeared at the same location as the first colored square than when it appeared at the opposite location. To confirm this, we conducted separate analyses of variance for younger adults and for older adults. Although for the younger adults, Stroop effects were larger for stimuli appearing at the same location as the first colored square, the interaction was not significant, $F(1, 15) = 0.81, ns, MSE = 1,469.37$, which is consistent with the interpretation that the effects of target side and congruency were independent. For the older adults, the interaction was significant, $F(1, 15) = 5.22, p < .05, MSE = 1,132.45$.

An analysis of variance on the proportion of errors produced a significant effect of age group, $F(1, 30) = 4.40, p = .04$; older adults had a higher proportion of errors ($M = .042, SD = .076$) than did younger adults ($M = .005, SD = .021$). No other effects were significant.

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[2] Experiments 5 and 6 were the only ones in which participants overlapped. All other experiments used unique samples of participants.
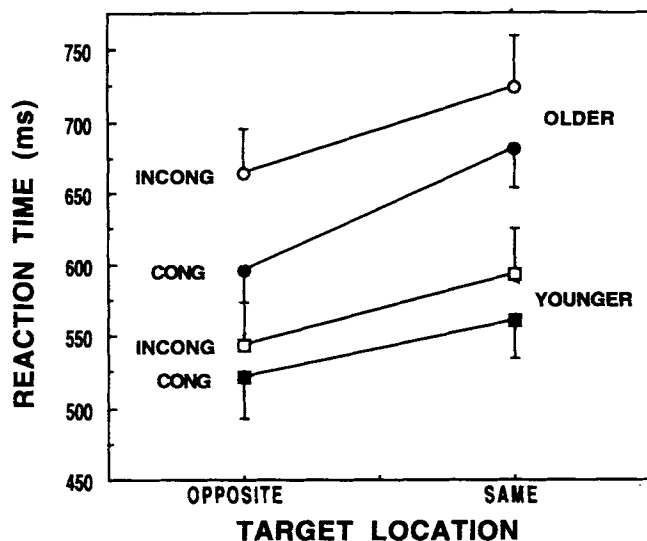
Figure 6. Mean reaction times (in milliseconds) in Experiment 6 as a function of age group, target location (ipsilateral or contralateral to the first target), and congruency. Cong = congruent; incong = incongruent. Bars show standard error.

Analyses were also carried out with the RTs in each condition expressed as a proportion of the grand mean for each subject. The overall analysis produced significant effects of target side, $F(1, 30) = 101.99, p < .001, MSE = 0.006$, and of congruency, $F(1, 30) = 45.58, p < .001, MSE = 0.006$. The interactions of age with these factors were attenuated: for age and target side, $F(1, 30) = 1.36, p = .25, MSE = 0.006$; for age and congruency, $F(1, 30) = 3.43, p = .07, MSE = 0.006$; and for age, target side, and congruency, $F(1, 30) = 3.72, p = .06, MSE = 0.004$. Separate analyses were also carried out on younger and older adults. The main effects of target side and congruency were confirmed in both groups: for younger adults for target side, $F(1, 30) = 56.40, p < .001, MSE = 0.004$, and for congruency, $F(1, 30) = 23.24, p < .001, MSE = 0.003$; for older adults for target side, $F(1, 30) = 49.10, p < .001, MSE = 0.006$, and for congruency, $F(1, 30) = 24.94, p < .001, MSE = 0.008$. Most important, the subadditive interaction of target side and congruency was found in the older adults, $F(1, 30) = 4.96, p < .05, MSE = 0.003$, but not in the younger adults, $F(1, 30) = 0.57, p = .46, MSE = 0.005$.

Discussion

The inhibition of return effect and the Stroop effect were additive in the younger adults, which is consistent with the interpretation that the two effects are independent. Although the means were in the direction of a superadditive interaction, consistent with the operation of a common mechanism in the two effects, the effect was not statistically reliable. In contrast, there was a subadditive interaction of the two effects in the older adults: The Stroop effect was smaller at the inhibited location. This result clearly falsifies the hypothesis that both of the effects are the result of some common mechanism in older adults, such as a reduction in the strategic suppression of attention. Follow-

ing additive factors logic, that hypothesis predicted a superadditive interaction in which the Stroop effect would be greater at the inhibited location. Because the strategic suppression of attention is thought to be an executive function subserved by anterior brain systems and because the interaction that was predicted if age differences in the suppression of attention were responsible for both effects was not found, the results are compatible with the explanation that age differences in the inhibition of return effect and in the Stroop effect result from different brain attentional systems. Because we failed to find evidence for anterior involvement, the results do not rule out the possibility that age differences in inhibition of return are due to changes in posterior brain systems.

The results once again fail to confirm the predictions of the general slowing hypothesis. Expressing the RTs as proportions of overall mean RT did attenuate the interactions of age with the inhibition of return effect and the Stroop effect. Although both were larger in older adults, they were not significantly larger. Nonetheless the three-way interaction of target side, congruency, and age remained significant. If two effects were independent in younger adults and if each effect was affected by general slowing in older adults, then the two effects would remain independent in older adults even though each effect would be absolutely larger. Here, the inhibition of return effect and the Stroop effect were independent in younger adults. They were not independent in younger adults. They were not independent in older adults, even when the RTs were expressed as proportions. If the results could be accounted for by general slowing, the two effects should also have been independent in older adults. They were not.

How can the results be explained? Subadditive interactions can result when two processes can be carried out in parallel (cf. Pashler, 1993; Stanovich & West, 1981). One speculation is that, in this experiment, slowing that was due to inhibition of return may have provided additional time for the interfering word to be filtered and the color to be processed, thus reducing the Stroop effect when stimuli appeared at a location to which attention had already been directed. If the slowing due to inhibition of return and the slowing due to Stroop interference occur in parallel, that would again be inconsistent with any common mechanism.

As in Experiment 5, the age groups differed in the proportion of errors. Once again, though, there was no interaction between the experimental variables and age group, so the interpretation of the RT results is not compromised.

Conclusions

The first four experiments showed that inhibition of return is as large, and probably larger, in older adults as in younger adults. Moreover, inhibition of return affects both detection and discrimination the same way in both age groups. There was evidence that it follows a similar time course and that it shows a similar spread in the visual field, although those conclusions are not based on powerful tests and should be interpreted with caution. If the effect is larger in older adults it could be that there are changes in posterior brain systems that mediate selective attention to spatial locations, contrary to Hartley's (1993) claim that those systems are relatively unaffected by aging. It was argued that posterior systems

could be preserved but that there are changes in the executive control of attention mediated by anterior brain systems. However, in Experiment 6 we used additive factors logic and failed to find evidence showing that the inhibition of return effect and the Stroop effect—a marker task for executive control of attention known to depend on anterior brain systems—shared a common mechanism. It is still possible to argue that the observed age differences in inhibition of return originate in the anterior attention systems. Paus et al. (1993) have shown a somatotopic organization of the ACC, an organization in terms of the output systems involved. In the combined task of Experiment 6, the Stroop component required suppression of a vocal response to the color word. The inhibition of return component required suppression of covert and overt orienting to a location. Although Paus et al. (1993) found that suppression of vocal responses and of oculomotor responses both produced activation in the rostral portion of the ACC, activation sites for speech were more caudal (primarily Brodmann's Area 24) than those for eye movements that were in the most anterior portion of the ACC (Brodmann's Areas 32 and 24). The extent to which activation in one area of the ACC affects activation in other areas is not known. Thus it is possible that suppression of vocal responses and of orienting could proceed independently. If this is the case, the Stroop effect and the inhibition of return effect could be empirically independent even if both are dependent on suppression mediated by the ACC.

The most parsimonious interpretation of the present results is that there are age-related changes in the functioning of posterior brain systems for selective attention to spatial locations, although this must remain a hypothesis. In one sense, the changes seem to be enhancements: Older adults take more advantage of cues and show greater resistance to returning to a previously attended location. Yet the implication is that attention may be more strongly captured and held by external stimuli in older adults than in younger adults. This could produce clear disadvantages in noticing and reacting to important environmental events.

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