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Overriding Age Differences in Attentional Capture With Top-Down Processing

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Abstract

Two experiments investigated the influence of top-down information on adult age differences in the ability to search for singleton targets using spatial cues. In Experiment 1, both younger and older adults were equally able to use target-related top-down information (target feature predictability) to avoid attentional capture by uninformative (25% valid) cues. However, during informative (75% valid) cue conditions, older adults demonstrated less efficient use of this cue-related top-down information. The authors extended these findings in Experiment 2 using cues that were either consistent or inconsistent with top-down feature settings. Results from this second experiment showed that although older adults were capable of avoiding attentional capture when provided with top-down information related to target features, capture effects for older adults were notably larger than those of younger adults when only bottom-up information was available. The authors suggest that older adults' ability to use top-down information during search to avoid or attend to cues may be resource-limited.

Keywords

aging; selective attention; attentional capture; reaction time; perception

The ability to efficiently search for and detect items in any environment is a function of two types of search processes, top-down and bottom-up. Bottom-up search processes detect local stimulus properties and are most efficient when properties of the target are distinct from the features of other items in a display or environment, such as a black tire on a white sandy beach (e.g., Treisman, 1988). Our environment, however, rarely consists of salient targets against homogeneous backgrounds. When target features are not highly distinct from nontargets in our environment, conceptual/knowledge-driven (top-down) search processes can set feature detection maps, facilitating detection of relevant target features (Müller, Heller, & Ziegler, 1995;Wolfe, 1994) and/or inhibiting irrelevant background information (e.g., Watson & Humphreys, 1997).

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Search tasks need not rely on either top-down or bottom-up processes exclusively; instead, both search processes may combine to guide search in a given task, with top-down contributions to search being strengthened by increasing observers' knowledge of target features (Whiting, Madden, Pierce, & Allen, 2005;Wolfe, Butcher, Lee, & Hyle, 2003). In a series of experiments, Wolfe et al. demonstrated that search for a target defined by a unique feature (i.e., a singleton) could be facilitated substantially if the defining target feature was known and remained constant (constant feature trials) within a block of trials, relative to blocks in which single target features were distinct but unpredictable (mixed feature trials). The use of a feature singleton in both types of search blocks allowed observers to use bottom-up information to locate targets. Reaction Time (RT) × Display Size slopes were either zero or negative for both constant and mixed feature trials, suggesting highly efficient search during both conditions. RT × Display Size intercepts, however, were significantly lower during constant feature search, illustrating the advantage of top-down processing even when search is highly efficient.

The effects of adult age on top-down processing during visual search were initially examined in tasks that led to significant display size effects, consistent with a difficult or inefficient search process (Humphrey & Kramer, 1997;Madden, Whiting, Cabeza, & Huettel, 2004). These studies reported patterns of search performance that were similar for younger and older adults, suggesting preservation of top-down function with age. In addition, top-down effects appear to include both an implicit (priming) and explicit (expectation) component, which are both generally preserved with age. In fact, under some conditions older adults appear to be engaging a larger explicit component under top-down conditions relative to younger adults (Madden, Whiting, Spaniol, & Bucur, 2005).

To isolate top-down search effects associated with age in the context of efficient search, Whiting et al. (2005) employed a singleton search paradigm such that target features were either constant or unpredictable within a block of trials. Replicating the Wolfe et al. (2003) findings, Whiting et al. found that the RT × Display Size slope was near zero for both predictable and unpredictable feature conditions, indicating that search was highly efficient. As in the Wolfe et al. studies, there was a robust top-down search effect, with RTs being much lower in constant, relative to mixed feature, search. More importantly, this top-down effect was similar for younger and older adults, indicating preserved top-down guidance with age in this form of efficient search.

In summary, recent research has indicated compelling evidence for age constancy in target detection based on top-down attentional guidance (Madden et al., 2004;Madden, Whiting, Spaniol, & Bucur, 2005;Whiting et al., 2005). In the present study, we investigated older adults' ability to efficiently use top-down information in additional facets of search tasks. In Experiment 1 observers used target-related top-down feature information to override bottom-up attentional capture by location-based onset cues during simple (highly efficient) search. On the one hand there is evidence that capture effects are driven primarily by bottom-up variables such as salience (Theeuwes, 1992,2004). Consistent with this account, some studies have indicated that older adults are more susceptible to attentional capture via onset cues during search compared to younger adults (Juola, Koshino, Warner, Mc-Mickell & Peterson, 2000;Kramer, Hahn, Irwin, & Theeuwes, 2000;Pratt & Bellomo, 1999), though Pratt and Bellomo have shown evidence for preserved top-down control settings in the same experiment. On the other hand, studies of younger adults indicate that top-down search appears to moderate or even override some capture effects (Ansorge & Heumann, 2003;Bacon & Egeth, 1994;Folk, Remington, & Johnson, 1992;Leber & Egeth, 2006). Peterson and Kramer (2001), for example, found that engaging in top-down, but not bottom-up, processes during search led to decreased attentional capture effects by onset stimuli. Similarly, some investigations of older adults report no age-related change in the magnitude of capture effects, which raises the possibility that older adults' use of top-down information may help prevent an age-related increase in capture in some contexts (Colcombe et al., 2003;Kramer, Hahn, Irwin, & Theeuwes, 1999).

We thus expected that older adults would be able to override attentional capture by nonpredictive cues when relevant target features were known (top-down conditions), but that older adults would be less able to do so when target features were uncertain (bottom-up conditions). A previous study by Whiting et al. (2005, Experiment 3) provided some preliminary evidence to suggest this may be the case, but inconsistent cuing effects and a relatively short stimulus-onset asynchrony between the cue and the display (150 ms) made the lack of an age difference in attentional capture difficult to interpret.[1] As an additional manipulation in the current experiments, in half of the trial blocks observers were instructed to pay attention to the location-based onset cues (informative blocks) because the cues reliably predicted target location (75% valid) compared to uninformative (25% valid) blocks. Attending to cues during informative conditions requires observers to set an additional top-down strategy of attending to the cues, in addition to monitoring target predictability. If maintenance of top-down goals during search requires attentional resources (e.g., De Jong, 2001), then older adults may experience greater difficulty maintaining both target and cue-related top-down goals during informative blocks. We thus expected either diminished cuing effects or smaller top-down target-related benefits in older adults during trial blocks in which the cue was informative compared to when it was uninformative.

To better characterize and expand findings of age-related effects in top-down control, in Experiment 2 we manipulated the degree to which a feature (color) of the cue matched top-down control settings of target features, as previous studies have shown that these settings modulate attentional capture (e.g., Folk et al., 1992). If older adults' ability to use top-down feature settings during search is intact, then older adults should be as sensitive to attentional capture by similarly colored cues and targets as younger adults.

Experiment 1

In Experiment 1 participants made a yes/no response regarding the presence of a target singleton in a four-item display. The singleton was a bar that differed in either color or orientation from three homogeneous, distractor bars. As with previous studies (Whiting et al., 2005;Wolfe et al., 2003), the relevant target feature was either constant within a block of trials (constant feature search), encouraging top-down search, or target features varied unpredictably within blocks (mixed feature search), encouraging bottom-up search.[2] Before each trial, an onset cue appeared that indicated the location of the target with the informativeness of cues manipulated across trial blocks.

If older adults are more susceptible than younger adults to bottom-up attentional capture (Juola et al., 2000;Pratt & Bellomo, 1999), then an age-related increase should occur in the capture effect (invalid cue RT – valid cue RT), in both the mixed and constant conditions, but the age difference should be most pronounced with uninformative cues in the mixed condition (which eliminates top-down contributions). If, in contrast, top-down processes are preserved with age (Madden et al., 2004;Madden, Whiting, Spaniol, & Bucur, 2005;Whiting et al., 2005), and these processes do attenuate capture effects, then age differences in the attentional capture effect should be smaller in magnitude in the constant feature condition than in the mixed feature condition. However, the maintenance of the additional top-down goal to attend to each cue during informative cue conditions is not resource free (Yantis & Jonides, 1990) and thus may

[1] Note that when spatial cuing tasks require a perceptual discrimination, the time-course for cuing effects is lengthened, and inhibition of return effects typically do not occur under 500 ms stimulus-onset asynchronies (Lupiáñez, Miffiken, Solano, Weaver, & Tipper, 2001).

[2] Bacon and Egeth (1994) have referred to these two search strategies as feature search mode and singleton detection mode, respectively.

create an additional executive burden on older adults' diminished executive resources (West, 2001). This burden may in turn affect older adults' ability to fully utilize these cues during informative cue conditions, constraining top-down benefits for older adults.

Method

Participants—Twenty-four younger adults between 18 and 22 years of age and 24 older adults between 60 and 77 years of age participated in Experiment 1. The older participants were healthy, community-dwelling individuals recruited via online campus notices and local newspaper ads. Younger participants were primarily university students who received extra credit in introductory psychology courses for participating. Corrected visual acuity was at least 20/40 for each participant, and all participants were screened for normal color vision using Ishihara color plates (Ishihara, 2003). Participant characteristics are presented in Table 1.

Apparatus and stimuli—Stimulus presentation and response collection were controlled by a 2.4 GHz Xeon-processor microcomputer with a Dell 19-in liquid crystal display monitor (1280 × 1024 pixel resolution; 60 Hz). On each trial, participants were presented with a display of four rectangular bars (see Figure 1). One of the four bars—the target singleton—differed from the other three homogeneous bars on the dimension of either color (red or green) or orientation (horizontal or vertical). Additionally, a single white square dot was present on each of two of the bars in the display; the task was to make a yes/no manual response as to whether or not the singleton contained a dot (cf. Wolfe et al., 2003). On half of the trials in a block, the target bar contained one of these white dots.

Participants viewed each display from a distance of approximately 60 cm. Display items were presented against a black background. Red (RGB = 255,0,0; CIE: $x = .635$, $y = .354$, luminance = 39.3 cd/m^2) and green (RGB = 0,164,0; CIE: $x = .281$, $y = .601$, luminance = 28.5 cd/m^2) bars were roughly similar in luminance as measured by a ColorVision (Lawrenceville, NJ) Spyder2PRO colorimeter. Both target and distractor bars were 1.7° × 0.38° of visual angle, and white (RGB = 255,255,255; CIE: $x = .317$, $y = .328$, luminance = 137.7 cd/m^2) dots were 0.38° × 0.38°, centered on the bar. Participants responded using the "Z" and "/" keys on the computer keyboard. The assignment of *yes* versus *no* responses to the two keys was counterbalanced across participants.

Target location was counterbalanced across a 2 × 2 cell grid spanning approximately 9° vertically and 10° horizontally, with each of the four bars appearing in each of the four quadrants. Within each quadrant, the position of each of the four bars was jittered randomly up to 0.3° both horizontally and vertically from the center of its cell. The onset cue presented before each display consisted of a light gray (RGB = 240,240,240; CIE: $x = .319$, $y = .328$, luminance = 119.2 cd/m^2) outlined box, 3.3° square with a 0.24° thick border centered around what would be the forthcoming target or distractor bar.

Design—Experiment 1 incorporated an Age Group (younger/older) × Search (constant/mixed feature) × Cue Validity (valid/invalid) × Cue Informativeness (informative/uninformative) mixed factor design. All variables, except age, were manipulated within-subjects. Though targets varied along the dimensions of color/orientation, this variable was included only to increase the unpredictability of the relevant target feature during mixed search and so was not analyzed as an independent variable; likewise, the presence or absence of dots on targets was used only so that all trials would contain a target. In total, participants completed 1,024 trials comprising 16 blocks of 64 trials each. The search variable reflected two different search conditions (eight blocks each). Under constant feature search, a target's relevant feature value (e.g., red) always remained constant within a block of trials, though the irrelevant feature value (horizontal or vertical) was allowed to vary. Each subject performed two blocks of constant feature search for each feature value (red, green, horizontal, and vertical). For the two blocks at each feature value, in one block the onset cues were informative regarding target location (i.e., cues reliably predicted target location, 75% valid) whereas in the other block the cues were uninformative (i.e., cues predicted target location at chance levels, 25% valid).

For the other eight blocks of trials, search was *mixed* in that the relevant target feature changed unpredictably along the four target feature values (red, green, horizontal, vertical). Each of these four feature values was equally represented within a trial block. As with constant feature search blocks, half of the mixed search blocks were informative. *Yes/no* trials were ordered randomly within trial blocks. Constant and mixed feature blocks always alternated, and four block orders were constructed to counterbalance the relative order of these two block types as well as the ordering of color versus orientation constant feature blocks. We also alternated cue informativeness across blocks.

Procedure—Each block of trials began with an instruction screen that contained information about the characteristics of the target within that block with respect to cue informativeness and search condition. Participants performed two practice blocks (32 trials each) of constant and mixed feature search before the test blocks. Each four-bar display remained on the screen until the participant responded with a *yes/no* decision or 6,000 ms elapsed. RTs were measured from display onset. Incorrect responses and failures to respond within the 6,000 ms response window were followed by the words “Error!” or “No response!” respectively, for 1,500 ms along with a tone. Halfway through the blocks, participants completed a demographic questionnaire and vocabulary subtest of the Shipley Institute of Living Scale (Shipley, 1967). At the end of the session, participants performed a computerized digit-symbol substitution test (Salthouse, 1992), a measure of elementary perceptual speed.

Results and Discussion

Error rate—Overall error rate (misses, false alarms, and response failures) was low, but the age difference was, nonetheless, significant, $F(1, 46) = 8.39$, $p < .01$, between younger adults (M = 4.0%, SD = 1.9%) and older adults (M = 2.5%, SD = 1.3%). Failures to respond were extremely rare (0.02% and 0.11% for younger and older adults, respectively). Miss and false alarm rates were 2.4 and 1.6% for younger and 1.4 and 1.0% for older adults, respectively. Because errors were so extremely low and not inconsistent with RT effects, error rates are not reported further.

RT—An Age Group (younger/older) × Cue Informativeness (informative/uninformative) × Search (constant/mixed feature) × Cue Validity (valid/invalid) mixed factor analysis of variance (ANOVA) was conducted on RTs by computing participants’ median RT in each task condition, and then computing means of these median RTs. This analysis was limited to correct responses (see Figure 2 for means). Significant interactions involving age were tested with a Brinley analysis to determine if the age difference could be accounted for by simple linear slowing with age (Brinley, 1965;Salthouse, 1985). This analysis involves obtaining mean RTs for each task condition and group. Using simple linear regression, younger adults’ means were used to predict those of the older adults. Returning to the Age Group × Task Condition ANOVA, younger adults’ RTs at the individual participant level were then transformed via the regression equation. The result was that the grand mean of younger adults becomes equivalent to the original grand mean of older adults. If following the RT transformation, an Age Group × Task Condition interaction remains significant, then the associated age difference is unlikely to be due to linear slowing with age (Madden, Pierce, & Allen, 1992).

With the exception of the cue informativeness effect, all main effects were significant. As expected, responses were faster for younger adults than for older adults, were faster when top-

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down processing was engaged during constant—relative to mixed feature—search, and were faster for validly cued than invalidly cued locations, all *Fs*(l, 46) > 78.0, $p < .001$.

Confirming findings of age-related preservation of top-down functioning during search (Madden et al., 2004;Madden, Whiting, Spaniol, & Bucur, 2005;Whiting et al., 2005), an Age × Search Type interaction, $F(1, 46) = 21.9$, $p < .001$, indicated that the top-down RT benefit (mixed minus constant feature RT) was greater in magnitude for older adults (700 ms) than younger adults (470 ms). After transforming younger adults' RTs by the linear regression slope and intercept of the associated Brinley function ($r^2 = .98$), this interaction was no longer significant, $F(1, 46) = 0.01$. Taken together, these findings still suggest that top-down processing remains intact with age, but that the greater top-down effect in older adults is best characterized by linear RT changes with age.

As noted in the Introduction, based on previous findings of larger automatic attentional capture effects in older adults (Juola et al., 2000;Pratt & Bellomo, 1999) for uninformative cue conditions, we expected potentially larger age differences in capture effects during mixed feature search when no top-down information was available but reasoned that older adults might be equally capable of avoiding attentional capture as younger adults when top-down strategies were available. To test this hypothesis, we conducted an a priori analysis (Age × Search × Cue Validity) of the uninformative condition only. A Search X Cue Validity interaction, $F(1, 46) = 4.27$, $p < .05$, confirmed that observers were better able to avoid attentional capture during top-down search, showing smaller cuing (cue validity) effects during constant (28 ms) versus mixed feature search (79 ms). This pattern of effects did not differ significantly between the two age groups.

Our omnibus ANOVA indicated a significant Age × Cue In-formativeness × Cue Validity interaction, $F(1, 46) = 5.63$, $p < .05$, that remained robust after the correction for general slowing, $F(1, 46) = 13.3$, $p < .001$. The previous findings of Yantis and Jonides (1990), showed faster target identification for valid cues during informative versus uninformative cue conditions, because knowing that cues were predictive resulted in additional voluntary attention devoted to the cues. For the same reason, the authors observed slower responses to invalid cues during informative relative to uninformative conditions. To further analyze our interaction, we directly compared the degree to which search for targets could be altered by the addition of top-down knowledge that cues were informative. For older adults, knowing that cues reliably predicted (informative conditions) target location did not result in a reliable RT benefit (uninformative – informative RT = 42 ms) for valid cues, or a significant cost (informative – uninformative = 17 ms) for invalid cues, though these numerical differences were in the expected directions. On the other hand, younger adults' RTs did vary significantly as a function of the top-down knowledge related to cue informativeness. During informative (compared to uninformative) conditions, younger adults' responses were 57 ms faster with valid cues, $t(23) = 2.61$, $p < .05$, and 67 ms slower with invalid cues, $t(23) = 3.38$, $p < .01$. These specific findings indicate that although younger and older adults may benefit equally from top-down knowledge of target features (in terms of the difference between the constant and mixed feature conditions), older adults are apparently less able to benefit from additional top-down knowledge related to the usefulness of cues.

Previous studies by Madden and colleagues have indicated that older adults are as capable of using top-down information to guide search as their younger counterparts (Madden et al., 2004;Madden, Whiting, Spaniol, & Bucur, 2005;Whiting et al., 2005). The present results, however, suggest that there are limitations to the amount of top-down information older adults can utilize during search. Although older adults were as effective as younger adults in using top-down information about target features to aid search and avoid attentional capture, younger adults relied to a greater extent on cue informativeness, and as a result, with increasing cue

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informativeness, both the benefit of valid cues and the disruption of search by invalid cues were greater for younger adults than for older adults.

Experiment 2

One explanation for the failure to find larger bottom-up attentional capture effects in older adults during uninformative conditions of Experiment 1 is that the grey onset cues used, though of higher luminance than targets and distractors, were not consistent with the attentional control settings used to locate colored targets, and so capture effects were rather small. Previous work has shown that capture effects are largely dependent on observers' top-down attentional goal settings, as reflected in the relation between cue and target features. Folk et al. (1992), for example, reported a contingent attentional capture effect: Observers searching for a target of known color were able to avoid attentional capture by uninformative cues, as long as the color of the onset cue was different from that of the target. When cue and target colors were the same, large cuing effects occurred even though the cues were irrelevant (Ansorge & Heumann, 2003;Bacon & Egeth, 1994;Leber & Egeth, 2006). Thus, top-down goals can enable efficient detection of targets but also facilitate processing of irrelevant items whose characteristics match top-down feature settings.

In an attempt to expand the test for preserved top-down functioning in older adults during search, we used colored cues in Experiment 2 that were either congruent with target-related top-down feature settings, congruent with distractor colors, or neutral (a different color altogether). We expected to observe larger cuing effects when the cue and target shared the same color, specifically during constant feature search in which top-down goals are set to a specific target feature value (e.g., blue). By contrast, cuing effects should be comparably smaller when the target and cue are different colors. Under the former conditions, attentional capture occurs because attention is set for a specific feature, even if included in a nonpredictive cue. Finding smaller attentional capture effects for older adults than for younger adults, with congruent cue and target colors, would suggest an age-related limitation in top-down attentional control settings.

Method

Participants—Twenty-four younger adults (19 to 23 years of age) and 24 older adults (60 to 80 years of age) participated in Experiment 2. Participant recruitment, visual acuity, and color vision requirement were the same as Experiment 1 (see Table 1).

Apparatus and stimuli—The task in Experiment 2 was identical to that in Experiment 1 with a few minor modifications. Because we were concerned that the vertical and horizontal line features of the cues might overlap with similar features in targets and distractor bars, we changed the shape of the cue from a square to a similarly sized circle (3.8° in diameter). Onset cue colors were either red (RGB = 235,25,25; CIE: x = .624, y = .354, luminance = 33.8 cd/m^2), blue (RGB = 0,122,255; CIE: x = .156, y = .161, luminance = 32.5 cd/m^2), or green (RGB = 13,150,13; CIE: x = .281, y = .593, luminance = 24.4 cd/m^2), and were roughly similar in luminance. The target and distractor bars also varied along these three color values.

Design and procedure—The design followed that of Experiment 1 with the addition of a cue (color) congruence variable. Cue congruence was manipulated so that the cue color either matched that of the upcoming target, distractor, or was a color not common to either the target or distractors. Levels of cue congruence were equally represented, randomly, in all trial blocks. Unlike Experiment 1, targets only differed from distractors on the dimension of color—on every trial the orientation of targets and distractors was the same, but these orientations were allowed to vary between trials.

Observers performed 12 blocks of 72 trials each. Half of the blocks were mixed, and half were constant feature search blocks. Observers performed two constant feature blocks for each of the three target colors, with each specific target color feature block performed under informative and uninformative conditions. During the six mixed feature blocks, the target color changed randomly from trial to trial, and half of these mixed blocks were performed under uninformative conditions.

The resulting design was an Age (younger/older) × Cue Informativeness (informative/uninformative) × Search (constant/mixed feature) × Cue Congruence (target/distractor/neutral congruent) × Cue Validity (valid/invalid) mixed factor design. All other variables were manipulated identically as in Experiment 1, and counterbalancing measures were likewise the same. Procedures were identical to those in Experiment 1. Participants were again told to either pay attention to (informative conditions) or ignore (uninformative conditions) the cues, regardless of their color.

Results and Discussion

Error rate—Error rates (misses, false alarms, plus response failures) were low and were not inconsistent with RT effects, and so are not discussed in detail. Further, younger (M = 2.8%, SD = 2.0%) and older adults' (M = 2.0%, SD = 1.4%) error rates did not differ significantly. Failures to respond were, again, rare (0.05% and 0.04% for younger and older adults, respectively). Miss and false alarm rates were 1.5% and 1.3% for younger adults, and 0.90% and 1.0% for older adults, respectively.

RT—Similar to Experiment 1, our RT ANOVA was based on median RTs from correct trials (see Table 2 for means). Independent variables included: age group, cue informativeness, search, cue congruence, and cue validity. Except for cue informativeness, all main effects were significant. Consistent with the findings from Experiment 1, main effects were again found for age group, cue validity, and search; all Fs(1, 46) > 14.0, $p < .001$. The effect of cue congruence, $F(2, 92) = 14.2$, $p < .001$, revealed that responses were generally slowest when cue and target color were congruent, followed by neutral cue-target congruence, and fastest when cues were congruent with distractor color.

Unless central to our research questions, we do not report lower order interactions when higher order interactions are significant, and significant age interactions were tested for linear slowing with age using the Brinley RT transform. Findings of a general preservation of top-down functioning with age followed exactly the same pattern as in Experiment 1. Though an Age Group × Search Type interaction suggested that older adults exhibited a greater top-down search benefit (i.e., RT difference between mixed and constant feature conditions) than did younger adults, $F(1, 46) = 19.2$, $p < .001$, this interaction did not survive the general slowing transformation; $r^2 = .94$, $F(1, 46) < 1.0$. So, although older adults may not benefit *more* from top-down search relative to younger adults, in both experiments we find no evidence of age-related impairment in the ability to use top-down information to guide feature detection.

As expected, a Search × Cue Congruence × Cue Validity interaction, $F(2, 92) = 3.50$, $p < .05$, indicated that attentional capture (cue validity) differences among cue congruence conditions occurred only when observers were engaged in top-down search, $F(2, 94) = 25.0$, $p < .001$, but not during bottom-up search. Specifically, during top-down constant feature conditions, cuing effects (invalid RT minus valid RT) were larger for target-congruent conditions (73 ms) than for distractor (22 ms) or neutral-congruent conditions (33 ms). This finding suggests that when observers knew the relevant target features and used that information to aid search, their attention was more strongly captured by cues that shared the relevant target feature/color, consistent with a contingent attentional capture effect (Ansorge & Heumann, 2003;Bacon & Egeth, 1994;Folk et al., 1992;Leber & Egeth, 2006). We find it interesting that whether or not the cues were informative seemed to have no effect on this pattern of attentional capture—apparently the top-down attentional control settings related to target features superceded top-down information related to the informativeness of the cues.

As with Experiment 1, an Age Group × Informativeness × Cue Validity interaction, $F(l, 46) = 5.44$, $p < .05$, survived the general slowing transformation, $F(l, 46) = 15.44$, $p < .001$. Cuing effects of both younger adults (24 ms) and older adults (32 ms) demonstrated that both groups ignored cues to the same degree during uninformative conditions, $F(l, 46) < 1.0$; during informative conditions, however, younger adults were marginally better able to make use of the cues as seen by their larger cuing effects (100 ms) compared to older adults (66 ms), $F(l, 46) = 3.09$, $p = .08$.

The central question of Experiment 2 was whether older adults would exhibit different attentional capture (i.e., cue validity) effects than younger adults when cue-target color congruence was the same versus different. An Age Group × Cue Congruence interaction, $F(2, 92) = 4.75$, $p = .01$, indicated that target-congruent trials were generally more difficult (resulting in longer responses) for older adults relative to other congruence conditions, but capture/cuing effects were otherwise constant across congruence conditions and age groups. For older adults, cue-target color congruence resulted in an RT increase (23 ms) relative to the neutral-congruent condition, $t(23) = 3.04$, $p < .01$, whereas no increase (0 ms) was observed for younger adults. Younger and older adults had equally faster responses (12 ms) during cue-distractor congruent conditions relative to the neutral condition. This Age Group × Cue Congruence interaction did not survive a general slowing transformation, $F(2, 92) = 1.86$, $p = .16$, suggesting that older adults' slowed responses when cue features matched those of targets was the result of the greater general difficulty searching for targets under these conditions.

An Age Group × Informativeness × Search × Cue Validity interaction, $F(l, 46) = 4.39$, $p < .05$, did survive a general slowing transformation, $F(l, 46) = 5.12$, $p < .05$, and suggests that age differences in cuing effects depend on top-down strategies at both the search type level and at the cue informativeness level (see Figure 3). Cuing effects in uninformative conditions reflect automatic and uncontrolled attentional capture. Under these conditions only older adults showed a Search Type × Cue Validity interaction, $F(l, 23) = 8.09$, $p < .01$, displaying minimal cuing effects (12 ms) during top-down constant feature search and comparatively larger effects during bottom-up mixed search (50 ms). Younger adults, on the other hand, showed consistent effects across constant (22 ms) and mixed feature (26 ms) search, $F(l, 23) = 0.12$, during uninformative conditions. This age difference suggests that older adults, but not younger adults, are using top-down processes during constant feature search to strategically avoid attentional capture by these uninformative cues, but when this information is not available (mixed search), older adults are less able to avoid attentional capture.

A different pattern emerged under informative cue conditions in which voluntary intentions to attend to cues tend to facilitate larger cuing effects (Yantis & Jonides, 1990). Older adults' cuing effects did not depend on whether they were engaged in top-down search (constant feature, 56 ms) or bottom-up search (mixed feature, 71 ms), $F(l, 23) < 1.0$. Younger adults, however, exhibited larger cuing effects during the mixed (120 ms) versus constant feature (81 ms) search; $F(l, 23) = 5.04$, $p < .05$. This result suggests that younger adults were better at attending to these informative cues. Cuing effects, thus, became larger for younger adults as the bottom-up nature of mixed search worked with top-down strategies to attend to cues. Note that this Age Group × Informativeness × Cue Validity interaction did not vary with search type in Experiment 1. We believe that the presence of this four-way interaction in the second experiment was augmented by changing the cue colors in Experiment 2 to better compete with top-down goal settings related to cue colors (e.g., Folk et al., 1992).

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As with Experiment 1, we also analyzed our four-way ANOVA to examine the influence of top-down cue informativeness (uninformative – informative RT) for each combination of age group, search type, and cue validity. As found in Experiment 1, only younger adults' RT was influenced by additional top-down knowledge of cue informativeness. This effect was indicated by a 46 ms RT cost (informative – uninformative RT) for invalidly (but not validly) cued trials, and only when younger adults were engaged in constant feature search; $t(23) = 2.24$, $p < .05$. This again confirms our other finding that younger adults were better able to make use of top-down knowledge related to cue informativeness especially when already engaged in top-down search strategies related to target features. The failure of younger adults to benefit from cue-related, top-down knowledge on validly cued trials during the same conditions may be due to a performance ceiling. For validly cued trials during constant feature search, younger adults' were demonstrating highly efficient search with roughly equivalent mean search times of only 594 ms and 582 ms for uninformative and informative conditions, respectively.

General Discussion

Confirming previous investigations of top-down processing during search (Madden et al., 2004;Madden, Whiting, Spaniol, & Bucur, 2005;Whiting et al., 2005), Experiments 1 and 2 both indicate that older adults and younger adults are equally capable of using top-down, target-related information during search, as reflected in the faster responses during constant feature blocks relative to mixed feature blocks. With respect to previous studies demonstrating greater susceptibility to attentional capture in older adults (Juola et al., 2000;Pratt & Bellomo, 1999), results from Experiments 1 and 2 revealed a general age constancy in attentional capture during uninformative cue conditions, consistent with previous studies (Colcombe et al., 2003;Kramer et al., 1999). When the cues in Experiment 1 were informative, however, younger adults attended to the cues to a greater degree than did older adults, suggesting an age-related decline in this form of top-down attention.

Bottom-Up Attentional Capture by Uninformative Cues

The primary goal of the present research was to examine the degree to which older adults might be able to override attentional capture when top-down strategies were employed. During Experiment 1, observers were better able to avoid attentional capture under uninformative cue conditions when engaged in top-down processing (constant feature condition) versus bottom-up processing (mixed feature condition). This ability to avoid attentional capture did not differ between the two age groups. Experiment 2 further tested the resilience of this effect using color cues that were identical in color to either distractors, targets, or neither (i.e., a neutral color). Target-congruent cues captured attention to a greater degree than neutral or distractor cues when top-down guidance of target detection was possible (constant feature search), exemplifying the contingent attentional capture effect described by Folk et al. (1992). However, cue congruence had no effect on attentional capture during mixed search when observers could not predict the color of targets. Together, these findings confirm that capture effects are dependent on attentional control settings (Ansorge & Heumann, 2003;Bacon & Egeth, 1994;Folk et al., 1992;Leber & Egeth, 2006) that do not differ between younger and older adults. Given that the cues in Experiment 1 were more luminant than target and distractor bars, it is difficult to characterize our capture effects in terms of cue salience (Theeuwes, 1992,2004).

The findings from Experiment 2 reinforced those from Experiment 1, indicating an age-related preservation of the ability to override attentional capture by uninformative cues, when engaged in top-down target-related processing. In fact, older adults may be more successful at avoiding uninformative cues when focusing on top-down information related to targets (constant feature search) compared to younger adults. The effects of increased reliance on top-down attention, however, are not entirely positive. When top-down target-related information was minimized, during the mixed feature search condition, older adults experienced greater attentional capture effects compared to younger adults (Juola et al., 2000;Kramer et al., 2000;Pratt & Bellomo, 1999) even though observers knew that the cues were uninformative. This increased reliance on top-down attention, on the part of older adults, may be a strategic shift to top-down strategies, when available, in order to counter deficiencies in bottom-up feature detection. This interpretation is consistent with neuroimaging research revealing possible deficits in bottom-up search processes with age (Madden, 2007;Madden, Whiting, & Huettel, 2005). Note that the tendency for older adults to rely on target-related top-down information to avoid attentional capture was only observed when cues were uninformative, and thus to be ignored.

Top-Down Voluntary Attention to Informative Cues

Cuing effects from informative cue conditions, on the other hand, represent observers' ability to devote voluntary attention to the cues. Though cuing effects observed during informative conditions are also due, in part, to an automatic bottom-up component, the cuing effects during informative conditions were three times larger than those during uninformative conditions. We attribute this difference to top-down strategies associated with using informative cues. These top-down strategies, however, are resource-dependent (Yantis & Jonides, 1990), which may explain why older adults had difficulty attending to both top-down goals related to cue informativeness *and* target feature settings, during informative conditions. Results from the informative conditions of both experiments revealed two important points related to age differences in the ability to use top-down processing: (a) In both experiments younger adults attended to informative cues to a greater degree than older adults; and (b) in Experiment 2, cuing effects were more prominent during mixed search compared to constant feature search, but this was only true for younger adults and not older adults.

The first point demonstrates that younger adults are able to attend to informative cues more so than older adults, suggesting that older adults have some difficulty using top-down strategies related to cue informativeness. There are at least two (not necessarily exclusive) explanations for this difficulty. One interpretation is that older adults may have concluded that attending to cues during informative conditions was less important than focusing on target identification, resulting in weak cuing effects. A second interpretation is that the combined strategies of focusing on both constant target features and the usefulness of the cues may have led to conflicting resource demands, which older adults were less successful at tolerating (cf. Reynolds, Donaldson, Wagner, & Braver, 2004). This last explanation is consistent with proposed age-related declines in executive functioning (De Jong, 2001;West, 2001). The fact that younger adults exhibited larger cuing effects during mixed search (relative to constant feature search) of informative conditions is consistent with a resource interpretation of cuing effects during informative conditions. Having no target-related top-down goal to maintain during mixed search should free-up attentional resources to be devoted to top-down goals related to the cues. The fact that this effect only occurred for younger adults suggests that cue-related top-down goals may be more resource intensive to maintain across trial blocks than target-related goals. Younger adults' potential for more efficient bottom-up processing might further enhance the effects of onset cues, during conditions promoting both bottom-up processing strategies (mixed search) and intentions to attend to cues (informative conditions).

Conclusions

Research from the past two decades has shown that both younger and older adults perform similarly on selective attention search tasks that require them to search for and identify a target among competing distractors. The present study contributes to this growing body of research by illustrating that top-down benefits, even in highly efficient search tasks, may be constrained by the resource load imposed by top-down search-related goals. When top-down search goals are few and easily executable, both younger and older adults should readily exhibit top-down search benefits, whereas increasing the number of top-down goals may place undue burdens on older adults' executive capacities, compromising the benefits of both top-down goals, or requiring older adults to reallocate resources in favor of one goal over another as shown in the present study. Viewed in this way, age differences in the execution of multiple top-down goals may be not unlike age differences observed in traditional resource-limited divided attention tasks (Madden & Whiting, 2004).

Our results regarding attentional capture were generally consistent between the two experiments. Experiment 1 provided evidence for age constancy in the more automatic form of capture (uninformative cue conditions) regardless of whether observers were engaged in top-down or bottom-up search. Experiment 2 replicated this pattern during top-down search, but showed older adults to be more susceptible to capture effects than younger adults when target detection was primarily bottom-up (mixed feature condition). Thus, both age groups appear to be equally adept at overriding attentional capture (uninformative conditions) when top-down guidance is available (constant feature search condition). Age differences were most prominent during informative cue conditions when two top-down search strategies had to be maintained (cue informative, constant feature search). Under such conditions, younger adults were better able to take advantage of top-down cue-related information compared to older adults. Thus, older adults' search performance can be aided by relevant top-down information, but only as long as the resource requirements for these top-down strategies do not conflict with other resource-dependent components of attention.

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References

Ansorge U, Heumann M. Top-down contingencies in peripheral cuing: The roles of color and location. Journal of Experimental Psychology: Human Perception and Performance 2003;29:937–948. [PubMed: 14585015]

Bacon WF, Egeth HE. Overriding stimulus-driven attentional capture. Perception & Psychophysics 1994;55:485–496. [PubMed: 8008550]

Brinley, JF. Cognitive sets, speed and accuracy of performance in the elderly. In: Welford, AT.; Birren, JE., editors. Behavior, aging, and the nervous system. Springfield, IL: Thomas; 1965. p. 114-149.

Colcombe AM, Kramer AF, Irwin DE, Peterson MS, Colcombe S, Hahn S. Age-related effects of attentional and oculomotor capture by onsets and color singletons as a function of experience. Acta Psychologica 2003;113:205–225. [PubMed: 12750049]

De Jong R. Adult age differences in goal activation and goal maintenance. European Journal of Cognitive Psychology 2001;13:71–89.

Folk CL, Remington RW, Johnson JC. Attentional capture by color and onset singletons in search tasks. Journal of Experimental Psychology: Human Perception and Performance 1992;18:1030–1044. [PubMed: 1431742]

Humphrey DG, Kramer AF. Age differences in visual search for feature, conjunction, and triple-conjunction targets. Psychology and Aging 1997;12:704–717. [PubMed: 9416638]

Ishihara, S. Ishihara's tests for colour deficiency: 24 plates edition. Tokyo: Kanehara Trading; 2003.

Juola JF, Koshino H, Warner CB, McMickell M, Peterson M. Automatic and voluntary control of attention in young and older adults. American Journal of Psychology 2000;113:159–178. [PubMed: 10862340]

Kramer AF, Hahn S, Irwin DE, Theeuwes J. Attentional capture and aging: Implications for visual search performance and oculomotor control. Psychology and Aging 1999;14:135–154. [PubMed: 10224638]

Kramer AF, Hahn S, Irwin DE, Theeuwes J. Age differences in the control of looking behavior: Do you know where your eyes have been? Psychological Science 2000;11:210–217. [PubMed: 11273405]

Leber AB, Egeth HE. It's under control: Top-down search strategies can override attentional capture. Psychonomic Bulletin & Review 2006;13:132–138. [PubMed: 16724780]

Lupiáñez J, Milliken B, Solano C, Weaver B, Tipper SP. On the strategic modulation of the time course of facilitation and inhibition of return. The Quarterly Journal of Experimental Psychology 2001;54A: 753–773.

Madden DJ. Aging and visual attention. Current Directions in Psychological Science 2007;16:70–74.

Madden DJ, Pierce TW, Allen PA. Adult age differences in attentional allocation during memory search. Psychology and Aging 1992;7:594–601. [PubMed: 1466828]

Madden, DJ.; Whiting, WL. Age-related changes in visual attention. In: Costa, PT.; Siegler, IC., editors. Recent advances in psychology and aging. Amsterdam: Elsevier; 2004. p. 41-88.

Madden DJ, Whiting WL, Cabeza R, Huettel SA. Age-related preservation of top-down attentional guidance during visual search. Psychology and Aging 2004;19:304–309. [PubMed: 15222823]

Madden, DJ.; Whiting, WL.; Huettel, SA. Age-related changes in neural activity during visual perception and attention. In: Cabeza, R.; Nyberg, L.; Park, D., editors. Cognitive neuroscience of aging: Linking cognitive and cerebral aging. New York: Oxford University Press; 2005. p. 157-185.

Madden DJ, Whiting WL, Spaniol J, Bucur B. Adult age differences in the implicit and explicit components of top-down attentional guidance during visual search. Psychology and Aging 2005;20:317–329. [PubMed: 16029095]

Müller HJ, Heller D, Ziegler J. Visual search for singleton feature targets within and across feature dimensions. Perception & Psychophysics 1995;57:1–17. [PubMed: 7885801]

Peterson MS, Kramer AF. Contextual cueing reduces interference from task-irrelevant onset distractors. Visual Cognition 2001;8:843–859.

Pratt J, Bellomo CN. Attentional capture in younger and older adults. Aging, Neuropsychology, and Cognition 1999;6:19–31.

Reynolds JR, Donaldson DI, Wagner AD, Braver TS. Item- and task-level processes in the left inferior prefrontal cortex: Positive and negative correlates of encoding. Neuroimage 2004;21:1472–1483. [PubMed: 15050572]

Salthouse, TA. Speed of behavior and its implications for cognition. In: Birren, JE.; Schaie, KW., editors. Handbook of the psychology of aging. 2. New York: Van Nostrand Reinhold; 1985. p. 400-426.

Salthouse TA. What do adult age differences in the digit symbol substitution test reflect? Journals of Gerontology, Series B: Psychological Sciences and Social Sciences 1992;47:P121–P128.

Shipley, WC. Shipley Institute of Living Scale: Administration form. Los Angeles: Western Psychological Services; 1967.

Theeuwes J. Perceptual selectivity for color and form. Perception & Psychophysics 1992;51:599–606. [PubMed: 1620571]

Theeuwes J. Top-down search strategies cannot override attentional capture. Psychonomic Bulletin & Review 2004;11:65–70. [PubMed: 15116988]

Treisman A. Features and objects: The fourteenth Barflett memorial lecture. Quarterly Journal of Experimental Psychology 1988;40A:201–237. [PubMed: 3406448]

Watson DG, Humphreys GW. Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. Psychological Review 1997;104:90–122. [PubMed: 9009881]

West R. The transient nature of executive control processes in younger and older adults. European Journal of Cognitive Psychology 2001;13:91–105.

Whiting WL, Madden DJ, Pierce TW, Allen PA. Searching from the top down: Aging and attentional guidance during singleton detection. Quarterly Journal of Experimental Psychology: Human Experimental Psychology 2005;58A:72–97.

Wolfe JM. Guided search 2.0: A revised model of visual search. Psychonomic Bulletin & Review 1994;1:202–238.

Wolfe JM, Butcher SJ, Lee C, Hyle M. Changing your mind: On the contributions of top-down and bottom-up guidance in visual search for feature singletons. Journal of Experimental Psychology: Human Perception and Performance 2003;29:483–502. [PubMed: 12760630]

Yantis S, Jonides J. Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance 1990;16:121–134. [PubMed: 2137514]

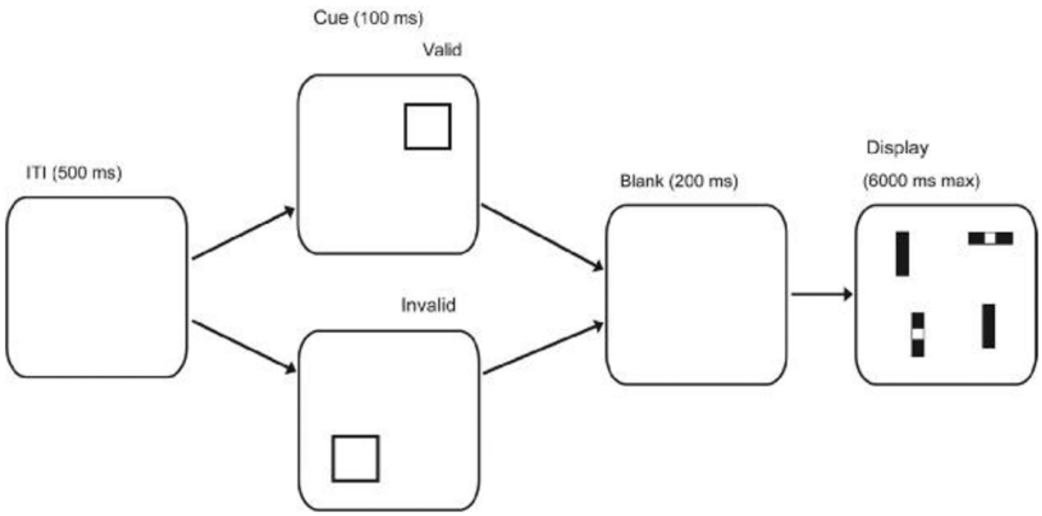

Figure 1.
Single trial presentation order and timing in Experiment 1. Note that a black background and colored items were used in the actual experiment.

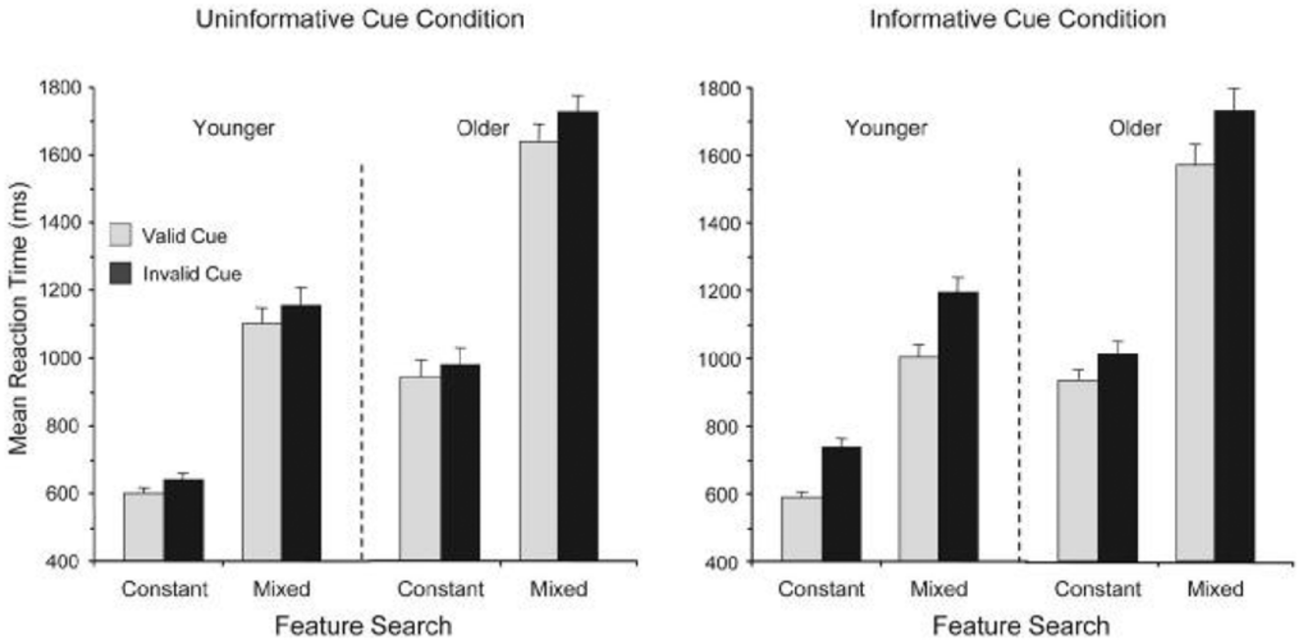

Figure 2.
Mean reaction times (± *SE*) in Experiment 1 as a function of age group, search condition, and cue validity for informative and uninformative cue conditions.

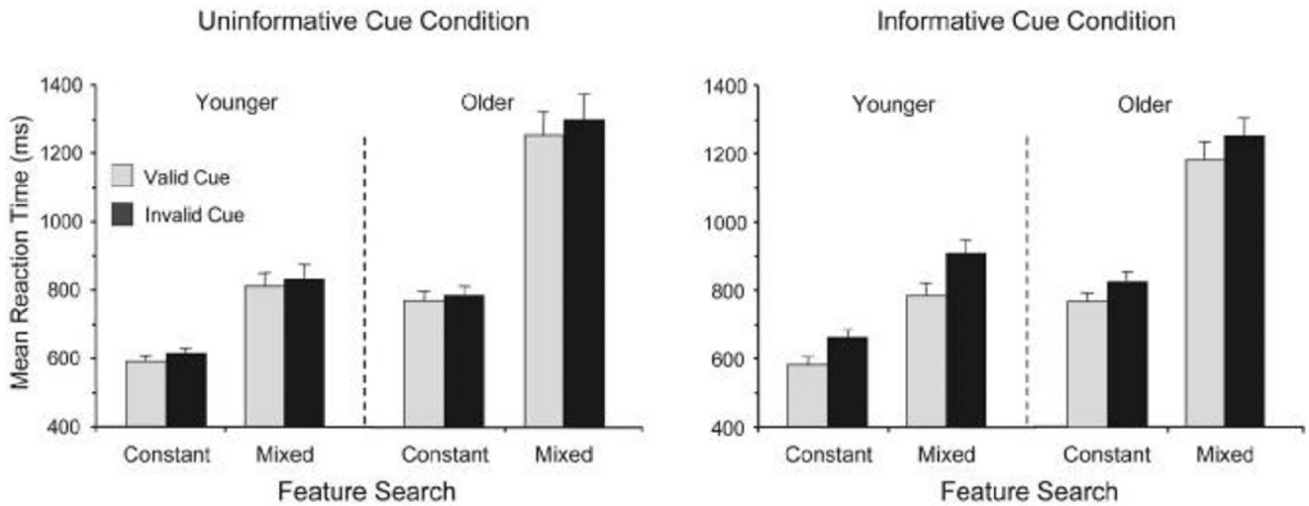

Figure 3.
Mean reaction times (± *SE*) in Experiment 2 as a function of age group, search condition, and cue validity for informative and uninformative cue conditions.

Table 1

Participant Characteristics

Variable	M		SD	
	Younger	Older	Younger	Older
		Experiment 1		
Age (in years)	19.5	64.1[a]	1.2	3.7
Education (in years)	13.1	17.3[a]	1.0	3.4
Vocabulary	33.0	35.4[a]	2.9	3.7
Acuity	20.6	22.3	6.6	5.3
Color vision	13.5	13.1	0.6	0.8
Digit symbol RT (ms)	1,336	1,924[a]	179	276
Digit symbol accuracy (% correct)	97.3	97.7	2.4	3.3
		Experiment 2		
Age (in years)	20.9	67.9[a]	1.0	5.1
Education (in years)	15.0	17.1[a]	0.8	3.1
Vocabulary	33.3	35.6[a]	3.0	4.0
Acuity	22.3	26.5	7.5	8.4
Color vision	13.6	12.9	0.6	0.8
Digit symbol RT (ms)	1,361	1,913[a]	185	345
Digit symbol accuracy (% correct)	97.5	96.0	2.8	12.0

Note. Vocabulary = Shipley Institute of Living Scale (Shipley, 1967) vocabulary subtest score (maximum of 40); Acuity = denominator of the Snellen fraction for distance vision (corrected); Color vision = number correct (maximum of 14) on the Ishihara (2003) color plates; Digit symbol RT = reaction time performance on a computerized test of digit-symbol coding (Salthouse, 1992).

[a]Age group comparison reliable at $p < .05$.

Table 2

Mean Reaction Times (+ SD) as a Function of Age Group, Search Condition, Cue Congruence, and Cue Validity for Informative and Uninformative Cue Conditions for Experiment 2

Cue congruence	Mean RT				SD			
	Constant feature		Mixed feature		Constant feature		Mixed feature	
	Valid	Invalid	Valid	Invalid	Valid	Invalid	Valid	Invalid
Uninformative cues								
Younger adults								
Target	586	626	812	831	81	82	212	188
Neutral	602	614	822	844	106	81	192	216
Distractor	594	610	795	834	84	84	204	228
Older adults								
Target	777	817	1,221	1,281	147	114	343	356
Neutral	781	782	1,207	1,252	135	132	384	380
Distractor	767	762	1,183	1,230	134	136	381	338
Informative cues								
Younger adults								
Target	575	688	794	920	111	117	151	213
Neutral	591	658	795	905	119	128	197	193
Distractor	582	644	779	902	111	118	162	168
Older adults								
Target	782	883	1,182	1,276	148	140	244	268
Neutral	766	819	1,186	1,236	127	127	270	245
Distractor	764	779	1,190	1,258	112	149	268	269