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Age-Related Preservation of Top-Down Control over Distraction in Visual Search

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Abstract

Visual search studies have demonstrated that older adults can have preserved or even increased top-down control over distraction. However, the results are mixed as to the extent of this age-related preservation. The present experiment assesses group differences in younger and older adults during visual search, with a task featuring two conditions offering varying degrees of top-down control over distraction. After controlling for generalized slowing, the analyses revealed that the age groups were equally capable of utilizing top-down control to minimize distraction. Furthermore, for both age groups, the distraction effect was manifested in a sustained manner across the reaction time distribution.

Keywords

aging; attention; visual search; singleton; distraction

Visual search, the selective search for target objects amongst non-targets, often requires the searcher to maintain attention for a target despite the presence of highly salient but task-irrelevant stimuli that can serve to disrupt attentional focus on the task goal. Exploring what factors do and do not lead to distraction can provide an important means to understand the cognitive processes involved in search. Two general classes of effects, bottom-up and top-down processes, are frequently viewed as essential to any theory of selective attention (Wolfe, 1998; Yantis & Egeth, 1999). Bottom-up processing involves sensory-level inputs that can automatically guide attention based upon feature saliency and top-down processing involves higher-order knowledge of the task parameters or goals.

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A key question that attention researchers have explored is whether bottom-up distraction is a fully automatic process, or whether its effects can be minimized by top-down control. The *contingent involuntary orienting* hypothesis proposes that bottom-up attentional capture can be attenuated by top-down control (Folk, Remington, & Johnston, 1992). According to this hypothesis, only stimuli that match the top-down representation of the task goals capture attention. Similarly, recent theories have suggested that changes in top-down attention may lead to corresponding changes in the effectiveness of salient nontargets. When observers adopt a *feature search* mode, search for a target is defined by a particular feature, and thus nontargets without this feature, though salient in other ways, can be effectively ignored. Observers may also adopt a *singleton detection* mode, however, preparing to detect any local stimulus change as a target, and in this case salient nontargets are more difficult to ignore (Bacon & Egeth, 1994; Leber & Egeth, 2006); but cf. (Theeuwes, Reimann, & Mortier, 2006; Theeuwes, 2004)

There have been few aging studies that have assessed top-down control of bottom-up distraction during visual search. This is surprising given that the issues of executive functioning and inhibitory control of distraction from irrelevant information figure prominently in aging research (e.g., McDowd & Shaw, 2000; Schneider & Pichora-Fuller, 2000). There is a host of age-related changes in sensory-level processing and elementary perceptual speed that can result in slower and less accurate visual search performance in older adults (Madden, 2007; Salthouse & Madden, 2007; Schneider & Pichora-Fuller, 2000; Scialfa, 2002). Evidence is mixed, however, regarding whether distraction by irrelevant stimuli has a specific role in the age-related changes. Whereas older adults exhibit declines in inhibiting task-irrelevant information in memory tasks (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; Zacks, Hasher, & Li, 2000), these age-related failures appear to be specific rather than widespread (Kramer & Madden, 2008). For instance, compared to younger adults, older adults have shown greater attentional capture by uninformative spatial cues (Pratt & Bellomo, 1999; Whiting, Madden, & Babcock, 2007; Whiting, Madden, Pierce, & Allen, 2005, Exp. 3) and increased reflexive eye movements for easily detectable task-irrelevant objects (Kramer, Hahn, Irwin, & Theeuwes, 2000). However, older adults have shown generally comparable improvements to younger adults in target identification using informative spatial cues (Hartley, Kieley, & Slabach, 1990; Madden & Whiting, 2004).

While loss of inhibitory control is common with older adults, such failures may not be a necessary consequence of aging. Across a comprehensive battery of inhibition tasks, Kramer et al. (Kramer, Humphrey, Larish, Logan, & Strayer, 1994) found broad age group equivalence in inhibitory control with tasks featuring response competition, negative priming effects and spatial precuing. Later studies by Kramer and colleagues examined age group differences in singleton search with task-irrelevant abrupt onsets and found broad evidence of age equivalence in oculomotor control when the stimulus sets were equiluminant (Kramer, Hahn, Irwin, & Theeuwes, 1999) but not when the distractors were of increased salience (Kramer et al., 2000). More recently, in a study assessing attentional capture by motion stimuli, there was no evidence (after accounting for generalized slowing and processing speed) of age group differences in distraction produced by new motion stimuli (Christ, Castel, & Abrams, 2008). The negative effect of age on inhibitory control, in other words, may be evident in working memory tasks more so than visual search tasks.

Age-related changes in visual distraction appear greatly influenced by task parameters, as older adults can emphasize top-down attention to a greater degree than younger adults (Madden, Whiting, Cabeza and Huettel, 2004; Madden, Spaniol, Bucur, & Whiting, 2007). Pratt and Bellomo (1999) speculated that older adults may rely on a feature search mode, under conditions in which younger adults use a singleton detection mode. According to this account, older adults implement top-down attention to a greater degree than younger adults but would be more vulnerable to distraction when a salient nontarget included the target-relevant feature. Older adults' ability to use top-down attention in this manner appears to represent an age-related increase in the top-down activation of target features that is independent of other aspects of performance improvement, such as repetition priming (Madden et al., 2007; Madden, Whiting, Spaniol, & Bucur, 2005).

It is surprising that older adults can show preserved reliance on top-down attention considering the well-documented age-related declines in *executive control*, including maintaining, selecting, and organizing task-relevant information (Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000; West & Schwarb, 2006; West & Bowry, 2005) and inhibition in memory tasks (Hasher et al., 1991; Hasher & Zacks, 1988; Zacks et al., 2000). Although previous experiments have demonstrated that older adults can have preserved top-down control in visual search, these studies have been limited in determining the age-related preservation of top-down control over singleton nontargets. In Madden et al. (2004), for example, participants searched for a target letter (an E or R) amongst three or five nontarget letters. Within each display was a color singleton that corresponded to the target letter in either an informative manner (guided condition) or uninformative manner (baseline condition). Thus, the guided condition provided prediction to target identity and served as top-down attentional guidance. Analyses of reaction time (RT) in the guided condition (compared to the baseline condition) indicated an age-related preservation of top-down control, as both older and younger adults exhibited RT decreases to singleton targets and RT increases to nonsingleton targets. Yet a limitation to their design is that a color singleton was present in each display, and thus the distraction associated with the singleton itself was not assessed. In addition, all trial blocks in the Madden et al. study included some trials in which the singleton and target corresponded, so color always retained some degree of task-relevance. Other studies of age group differences in top-down control have similarly not determined the unique effect of singleton nontarget distractibility, for the source of distraction was a spatial cue rather than a display element that required the same type of identification processes as the target (Pratt & Bellomo, 1999; Whiting et al., 2007; Whiting et al., 2005).

In the present experiment we sought to develop a stronger test of older adults' ability to use top-down attention to avoid distraction by irrelevant, but salient, nontarget items. In particular, we provided a condition in which a salient display item—a color singleton—would never correspond to the target. Thus, in contrast to previous studies of age differences, we provided a reliable basis for a top-down attentional set to reduce the effects of the color singleton because this item would (in this condition) never be the target (Theeuwes & Burger, 1998). As a comparison condition, in separate blocks of trials, the color singleton would on some trials correspond to the target. In this latter condition, however, the color singleton-targets did not occur sufficiently often that color was informative regarding target location; that is, the singleton was usually a nontarget. When the color singleton is a nontarget, RT is likely to be higher than when either the singleton is the target or no singleton is present. When the color singleton is the target, however, RT may actually be less than no-singleton trials, as a result of the influence of the bottom-up salience on top-down attention (Proulx, 2007). For instance, experiments with younger adults have suggested that detection is faster for color singleton-targets than for displays without a singleton, even when color is not informative regarding the target (Yantis & Egeth, 1999; comparing experiments 1 & 3). Thus, within each level of top-down attention we were able to determine whether the color singleton has a potential benefit as well as a cost.

Based on previous demonstrations that older adults are successful in using top-down attention to guide visual search (Madden et al., 2007; Madden et al., 2004; Madden et al., 2005; Whiting et al., 2005), we hypothesized that both younger and older adults would be successful in using top-down attention to avoid distraction from a salient nontarget. Specifically, the increase in

RT when the color singleton was not the target (i.e., singleton nontarget trials) would be reduced, for both age groups, when the task specified that the singleton would never be the target, relative to when it could sometimes be the target. Theories based on age-related decline in executive functioning would predict a more pronounced distraction effect for older adults than for younger adults, because older adults would be assumed to be less effective at using the task structure to attend selectively to the target (Wecker et al., 2000; West & Bowry, 2005; West & Schwarb, 2006). We also expected that whatever beneficial effects were associated with singleton-target correspondence, relative to no-singleton target trials (Yantis & Egeth, 1999) would accrue to both younger and older adults.

No research to date has identified whether age group differences in distraction inhibition might lie in its differential effect across the RT distribution. Distraction may be an automatic phenomenon that decays quickly over the response period (e.g., Eimer, Hommel, & Prinz, 1995; Hommel, 1993) and therefore its effects may be weighted more heavily at the earliest (faster) locations along the RT distribution. Conversely, distraction may operate throughout the RT distribution, with an effect that does not decrease following the earlier locations, indicative of a more sustained influence on performance. Furthermore, by comparing the time courses between the *never* and *sometimes* conditions, we might identify whether there are age group differences in the application of top-down control of distraction. Top-down control may be evident with varying degrees of potency along the RT distribution, and this differential weighting may be sensitive to age effects. Previous analyses of RT distributions have been valuable in discriminating *sustained* attentional effects (i.e., those that either remain constant or increase in magnitude across percentiles) from those that are more *transient* (i.e., those that are present in the faster responses but not thereafter; cf. Wiegand & Wascher, 2005). Thus a goal of our study is to determine the transient or sustained effects of both distraction and top-down control over distraction, and whether there are age-related changes over in these effects.

To obtain this finer-grained estimate of top-down control over distraction, we assessed the duration of distraction within trials as well as the average magnitude of distraction across trials. To do this we analyzed the complete distribution of RTs (represented by cumulative percentile bins, from fastest responses to slowest) at the individual participant level. In a recent study of spatial incompatibility (Simon effect), for example, Castel, Balota, Hutchinson, Logan, and Yap (2007) reported that the magnitude of the incompatibility effect was more sustained for older adults than for younger adults. Thus, in the present experiment, if distraction by a salient nontarget is a sustained attentional effect, we would expect that the increase in RT associated with the singleton would be evident across the entire RT distribution. Similarly, a differential effect of distraction in older adults' effortful allocation of attention would be evident as an age-related increase in the sustained effect; that is, an increase in the distraction effect in the higher segments of the distribution (slower responses) for older adults relative to younger adults. Such an outcome would be expected if, for example, distraction was more attention-demanding for older adults and led to an increase in the proportion of extremely slow responses.

Method

Participants

The Institutional Review Board of the Duke University Medical Center approved the research procedures and all the participants gave written informed consent. There were 24 participants (12 women) in each of the two age groups: younger adults between 18 and 29 years of age (M = 21.1 years, SD = 3.0) and older adults between 60 and 89 years of age (M = 68.3 years, SD = 6.1). All participants had normal color vision, with a score of at least 12 (out of 14) on the Dvorine color plates (Dvorine, 1963), and had a minimum acuity of 20/40. The participants were community-dwelling individuals who were free of significant health problems (including hypertension, atherosclerosis, epilepsy and psychiatric disorders), as determined by a screening questionnaire. The two age groups were comparable in their performance on the Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revisited (WAIS-R; Wechsler, 1981). See Table 1 for demographic information on the two groups.

Apparatus and Stimuli

As illustrated in Figure 1, each display contained one circle (the target) and several nontarget shapes (squares). Each of the display items (including both the target and the nontargets) contained either a plus symbol (+) or an equal symbol (=), and the participants' task was to make a two-alternative forced choice response regarding which of these two symbols was located in the target circle. The stimuli were displayed on a 20-in flat panel computer monitor. Viewing distance was approximately 60 cm. Displays consisted of 4, 6, 8, or 12 shapes distributed in a rectangular grid. The diameter of the circle was 1.2° and the sides of the nontarget squares were each 1.2°. The interior plus and equal symbols were 0.61° wide. Display items were separated by at least 0.61°.

Displays were created using an invisible 2 × 2 grid (8.5° × 8.5°) for balancing spatial locations of display items. Equal numbers of shapes were placed in each quadrant of the 2 × 2 grid (e.g., one shape per quadrant for display size 4) except for display size 6, in which case two quadrants contained one shape and two quadrants each contained two shapes. All displays contained equal numbers of +/= symbols. Participant responses for these symbols were assigned to either the *z*-key or/-key, with this assignment balanced across participants, within each age group. The shapes were presented as color outlines against a black background. The test trials were divided into two separate task conditions that varied the role of color in the search task. Within each condition, half of the trials contained a color singleton (always a red shape among green shapes), and half did not contain a color singleton (all shapes were green). The red (RGB = 255, 0, 25) and green (RGB = 25, 150, 25) colors were of similar luminance, approximately 6.5 fL., and to ensure color and luminance consistency the testing monitor was calibrated regularly using Spyder Pro2 (http://spyder.datacolor.com/index_us.php). The plus symbol or equal symbol within each shape was always the same color as the associated shape.

The task conditions differed with regard to whether the color singleton could also be the target, thereby providing a measure of top-down control. In the *never* condition, participants were instructed that the color singleton was never the target, whereas in the *sometimes* condition the color singleton could be the target at an uninformative rate ($1/n$ trials, where n = display size) and was therefore not informative regarding which shape was the target. The experiment was composed of 12 blocked conditions (6 *never* and 6 *sometimes* blocks) of 64 trials each (768 trials total). Within each block of 64 trials, there were eight trials, distributed randomly, for each combination of the four display sizes and two singleton (present, absent) conditions. Across these eight trials, the target circle was located in each quadrant of the grid twice. For these latter two occurrences, one target contained a plus symbol, and one contained an equal symbol. There were two run orders established with reversed presentation of alternating *never* and *sometimes* condition blocks, with this assignment balanced with regard to response assignment.

Procedure

Participants were instructed to report the symbol ('+' or '=') within the circle by pressing the appropriate response key, with equivalent emphasis on both accuracy and speed. On each trial, the display remained on the screen until the participant's response, up to a maximum of 3 s. Trials for which this limit was exceeded were followed by a visual prompt that asked the participant to respond more quickly. Following correct responses, a blank screen occurred, for a variable duration of 1200–1800 ms, which was then followed by the display for the next trial. On incorrect trials, there was visual feedback for 1000 ms ("incorrect"), followed by a blank screen for 200–800 ms, before the display for the next trial. An instruction screen occurring before each block indicated the upcoming task condition, and reappeared again, halfway through each block, as an additional reminder. Prior to testing, participants were instructed on the task and performed a practice block consisting of one *never* block of 32 trials and one *sometimes* block of 32 trials, yielding a total of 64 practice trials. Both younger and older adults performed well in the practice block (younger = 98%; older = 95%), with no participant under 80% accuracy for either block condition.

Results

Accuracy

Trials with RTs less than 200 ms (<3%) were dropped from all analyses. Also dropped from the main analyses were all trials on which the color singleton was the target and the immediately following post-singleton target trial, the reason for which will be described in the following paragraph. After these eliminations, accuracy was high for both older adults (M = 98.9%, SD = 1.7%) and younger adults (M = 98.1%, SD = 2.4%). Accuracy on the excluded trials was slightly reduced, but similar for older adults (M = 96.3%, SD = 8.0%) and younger adults (M = 97.3%, SD = 6.2%).

Raw Reaction Time

The following analyses of RT were performed on all trials over 200 ms, excluding the singleton-target trials and the trial immediately following each singleton target in the *sometimes* condition. Such trials comprised <8% of all trials per participant. We excluded the singleton-target trials so that the comparison between the two conditions (*never*, *sometimes*) would be based on trials that were identical in physical structure (i.e., including color singleton non-target trials but never color singleton-target trials). Furthermore, as shall be detailed later, we found that RTs increased significantly on color singleton-target trials and the trial immediately following a color singleton target; accordingly we excluded such trials from the main analyses, with separate analyses for them later.

An analysis of variance (ANOVA) was conducted on the mean of the median of the RT for correctly performed trials (as described in the previous paragraph) within each task condition for each participant. These values are presented in Figure 2. Variables included age group (older, younger), condition (*never*, *sometimes*), display size (4, 6, 8, 12), and distraction (present, absent). All of the main effects were significant: age group, $F(1, 46) = 90.60$, $p < .0001$, with younger adults faster than older adults; condition, $F(1, 46) = 56.30$, $p < .0001$, with the *never* condition faster than the *sometimes* condition; display size, $F(3, 138) = 165.62$, $p < .0001$, with lower display sizes faster than higher display sizes; and for distraction, $F(1, 46) = 115.09$, $p < .0001$, with non-distraction trials faster than distraction trials.

There were several significant interactions in the analysis of the raw RTs. There was an Age Group × Display Size interaction, $F(3, 138) = 7.20$, $p < .001$, with older adults evidencing a steeper slope of the RT × Display Size function than younger adults, an effect we will analyze more closely in the following paragraph. There was an Age Group × Distraction interaction, $F(1, 46) = 7.58$, $p < .01$, with older adults exhibiting a greater distraction effect than younger adults. There was a Display Size × Distraction interaction, $F(3, 138) = 17.26$, $p < .0001$, with the distraction effect strongest at display size 12 compared to the other display sizes. There was a Condition × Display Size interaction, F(3, 138) = 3.58, $p < .05$, with the condition difference smallest at display size 6 compared to the other display sizes. There was a Condition × Distraction interaction, $F(1, 46) = 12.14$, $p < .01$, with the distraction effect larger in the *sometimes* condition compared to the *never* condition. Finally, there was a Condition × Display

Size Distraction interaction, $F(3, 138) = 7.00$, $p < .001$, driven by a drop in distraction effect at display size 8 in the *never* condition compared to all other display size and conditions.

Given that RT increased with increasing display size, we analyzed differences in the linear RT × Display Size slope for the age groups and task conditions. The RT slopes were obtained for each participant and analyzed by ANOVA with age group, condition, and distraction as independent variables. Age group was significant, $F(1, 46) = 12.17$, $p < .01$), with steeper slopes for older adults ($M = 13.76$ ms per item, $SD = 9.11$) compared to younger adults ($M = 9.11$ ms per item, $SD = 6.41$). Distraction was also significant, $F(1, 46) = 22.79$, $p < .0001$, with distraction present trials exhibiting steeper slopes ($M = 13.68$ ms per item, $SD = 8.96$) than no-distraction trials ($M = 9.19$ ms per item, $SD = 6.68$). There was an Age Group × Condition interaction for search slopes, $F(1, 46) = 4.20$, $p < .05$, but this represents relatively small changes in the slopes, a 2 ms per item increase in slope for the *sometimes* condition relative to the *never* condition for older adults, whereas the younger adults exhibited a 2 ms slope decrease between conditions. For each combination of age group, condition, and distraction, the individual slopes were greater than zero at $p > .05$ (one-tailed).

Standardized RT

We have reported (above) both the main and interactive effects of the raw RT analyses in order to provide the fullest portrait of the dataset. However, the interpretation of age group effects in raw RT is complicated by the well documented generalized slowing associated with aging, which can magnify task condition effects associated with higher RTs (Salthouse, 1985; Salthouse & Madden, 2007). To control for generalized age-related slowing, we used a *z*-score transform of the RT data (Faust, Balota, Spieler, & Ferraro, 1999). For each participant, we first derived the mean and standard deviation of RTs for all correct responses. We then defined *z*-scores for the individual trial RTs, based on these means and standard deviations. Thus, individual trial *z*-scores greater than zero represent slower performance than the participant's mean, whereas *z*-scores less than zero represent faster performance. The means of these standardized values are presented in Figure 3.

We performed an ANOVA on these standardized RT values, with age group, condition, display size, and distraction as variables, excluding singleton-target and first post-singleton-target trials as detailed above. The *z*-score definition, however, included these trials as the mean RT value used to calculate the *z*-score should include all trials within the testing session (cf. Faust, Balota, Spieler, & Ferraro, 1999). The main effect of age group was not significant, a necessary consequence of the standardization procedure. There was a significant effect of condition, $F(1, 46) = 41.61$, $p < .0001$, with responses in the *never* condition ($M = -.07$, $SD = .23$) faster than those in the *sometimes* condition ($M = .04$, $SD = .26$). Display size was also significant, $F(3, 138) = 125.72$, $p < .0001$, with increasing display size associated with increasingly slower RTs. Responses on distraction trials ($M = .12$, $SD = .24$) were significantly slower than those on no-distraction trials ($M = -.15$, $SD = .18$), $F(1, 46) = 142.95$, $p < .0001$.

There was a Display Size × Distraction effect, $F(3, 138) = 19.51$, $p < .0001$, representing more pronounced distraction effects (i.e., distractor present trial *z*RT minus distractor absent trial *z*RT) in display sizes 6 and 12, relative to display sizes 4 and 8. There was a Condition x Display Size interaction, $F(3, 138) = 8.54$, $p < .0001$, with the condition effect (*sometimes* *z*RT – *never* *z*RT) smallest in magnitude at display size 6 ($M = .04$) and larger in the other display sizes ($M > .12$). There was a significant Condition × Distraction effect, $F(1, 46) = 12.23$, $p < .01$, with the distraction effect (as expressed in distraction present *z*RT – distraction absent *z*RT) greater in the *sometimes* condition (.32 difference) compared to the *never* condition (.24 difference). Importantly, there were no age group interactions[1].

Effect of Color Singleton Targets on Neighboring Trials

In the *sometimes* condition, RTs and error rates increased on singleton-target trials, with a continued negative effect on the immediately following trial. To explore this effect, we analyzed the *z*RT values for the sequence of trials extending two trials before, and two trials after, the occurrence of a color singleton-target. Given the low number of such trials (30 per participant), the neighboring positions were collapsed across distraction present and no-distraction conditions.[2] Mean values are presented in Figure 4. An ANOVA on these *z*RT values with age group and position as the independent variables yielded a position main effect, $F(4, 184) = 23.91$, $p < .0001$. Bonferroni comparisons ($p < .05$) revealed that responses at position 0 (singleton target trial) were significantly slower than at position +1, and that responses at both of these positions were slower than at all the remaining neighboring positions. There was no main effect or interaction involving age group.

Color Singletons

The color singleton target analyses indicated that, contrary to expectation, both age groups exhibited a performance decrease when the target was also the color singleton. To analyze the differential effects of the color singleton in all its manifestations in the task, we sorted the color singleton-present trials into three categories: 1) *never* condition (color singleton nontarget); 2) *sometimes* condition (color singleton nontarget); and 3) *sometimes* condition (color singleton target). For each participant, we derived summary variables of mean *z*RT, collapsed across display size, for these three color singleton trial types (excluding the 1st post-singleton target trials). ANOVA results of these *z*RT values indicated a significant effect of color singleton type, $F(2, 92) = 26.64$, $p < .0001$ (*never* condition, nontargets color singletons $M = .04$, $SD = .13$; *sometimes* nontargets color singletons $M = .20$, $SD = .12$; *sometimes* color target singletons $M = .42$, $SD = .37$). Bonferroni-corrected paired comparisons indicated that a minimum difference of .13 *z*RT units was significant for $t(92) > 2.44$ at alpha = .05. Each of the paired comparisons of the three conditions was significant at this level.

Throughout this comparison of the zRT values within the *never* and *sometimes* conditions, there was no Age Group × Distraction interaction, indicating that the effect of distraction was comparable for younger and older adults.

Binned Analyses of Distraction Effect

As described in the Introduction, we examined whether the distraction effect was a transient or sustained moderator of performance. Following the approach used in Castel et al. (2007), mean RTs were sorted into 20th, 40th, 60th, and 80th percentile bins, for each participant, by condition (*never*, *sometimes*) and distraction (absent, present), excluding the color singleton-target and 1st-post-singleton target trials. We then derived distraction effect summary variables for each participant by subtracting the percentile RT value on no-distraction trials from the percentile RT in the corresponding bin on distraction present trials. Raw RT was used rather

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[1]Compatibility effects between the symbols (+, =) located within the targets and distractors (i.e., color singletons) were also analyzed, sorting trials into compatible trials (same symbol for target and distractor), incompatible trials (different symbols for target and distractor), and no-distraction trials. An ANOVA on zRT found a significant effect for compatibility, $F(1, 46) = 107.50$, $p < .0001$, and a Condition x Compatibility interaction, $F(2, 96) = 22.69$, $p < .0001$. Bonferroni paired comparisons, $t(48) > 2.84$, $p < .05$, indicated that, in the *sometimes* condition, responses on both compatible and incompatible trials were slower than on the no-distraction trials, but the two compatibility conditions did not differ significantly. In the *never* condition, in contrast, *z*RT for both compatibility types was again higher than for no-distraction trials, but an additional slowing was evident when the target and color singleton were response-incompatible. There were no age group main or interactive effects for compatibility.

[2]We conducted additional ANOVAs with the neighboring positions as 1) only distraction (color singleton nontarget) trials, and 2) only no-distraction (no color singleton) trials. The results for each were similar to those obtained when averaging across these two trial types: 1) no age group main effects, 2) no Age Group x Position interactions, 3) a strong position main effect ($p < .0001$). The distraction and non-distraction trials contributed roughly equivalently to the main analyses, with non-distraction trials comprising 56% at position −2, 49% at position −1, 55% at position +1, and 62% at position +2, similarly for the two age groups.

than standardized RT because the transient vs. sustained contrast analyses the temporal distribution of the distraction effect, an analysis not conducive to the purely Gaussian distribution of standardized RTs (cf. Castel et al., 2007; Proctor, Pick, Vu, & Anderson, 2005; Wiegand & Wascher, 2005).

The results are presented in Figure 5. In a 2 (age group) × 2 (condition) × 4 (bins) ANOVA, age group was significant, $F(1, 46) = 3.90$, $p = .05$, with older adults showing a greater distraction effect than younger adults. This age group effect is not surprising, given that this type of analysis involves raw RT, rather than standardized RT. As evident in Figure 6, the magnitude of the distraction effect increased as a function of increasing bin, $F(3, 138) = 42.83$, $p < .0001$, with a linear rise across the percentiles. There was a Condition x Bin interaction, $F(3, 138) = 3.02$, $p < .05$, with reduced distraction effect values for the *never* condition, relative to the *sometimes* condition ($p < .05$), only for the 20th and 40th percentiles. There were no significant age group interactions[3].

Discussion

Our task design offered two conditions with varying degrees of top-down control over distracting color singletons. In the *never* condition, participants know that the color singleton will never be the target and can therefore prepare to ignore it, whereas in the *sometimes* condition the attentional set must allow color singletons as possible targets. Contrary to predictions based upon theories of widespread age-related failures of inhibition (Hasher & Zacks, 1988) and executive functioning (Wecker et al., 2000; West & Bowry, 2005), older adults displayed reduced *z*RTs in the *never* condition compared to the *sometimes* condition, in accordance to our original prediction of top-down preservation in aging. Several recent studies have similarly suggested that older adults are not differentially affected by distraction (Christ et al., 2008) and display age-related preservation of top-down mitigation of bottom-up distraction (Lorenzo-Lopez, Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Madden et al., 2004; Whiting et al., 2005; Whiting et al., 2007). This age group equivalence in the distraction effect may be limited to particular stimuli types, as the aforementioned studies used either non-verbal (Lorenzo-Lopez et al., 2007; Whiting et al, 2005; Whiting et al., 2007) or simple letter or number stimuli (Christ et al., 2008; Madden et al., 2004). Conversely, a recent distraction task found an age-related increase in distraction from irrelevant words (Kim, Hasher, & Zacks, 2007), and such verbal stimuli may draw on frontal brain regions more susceptible to age-related decline (West, 1996).

While this overall finding of broad age group equivalence in minimizing the distraction effect is valuable, our analyses examined further into the possibilities of age group differences in the application of top-down control, as evidenced by the binned distraction effect RT analyses. As discussed in the Introduction, the effects of both distraction and top-down control may be most evident in the fastest responses and then decrease at the slower responses (i.e., transient effects), or it may be sustained across all response durations (i.e., sustained effects). The gradually increasing slopes of the distraction effect across the binned RT in Figure 5 indicate that distraction was manifest (for both age groups) as a sustained effect. The only age effect evident in Figure 5 is that the older adults yielded consistently higher distraction effect values compared to the younger adults. Yet the increasing slopes of distraction effect across percentile bins were equivalent to the two age groups. The effect of distraction in our task, furthermore, lay more at the input level rather than the response competition level, given that the occurrence of the

[3]Because RT generally increases with display size, the increase in RT with percentile bin may simply reflect the influence of display size. To rule out this possibility, these same analyses were run separately by display size, and yielded similar results: 1) older adults yielding consistently higher distraction effect compared to younger adults, and 2) increasing distraction effect with increasing bin. Thus, the binned analyses are not equivalent to display size effects but represent dynamics inherent across them.

color singleton distractor was not informative regarding either target location or the +/= response. Thus, although the distractor may have slowed some of the attentional (controlled) processing of the display, as evident in the sustained effect, the source of distraction was primarily bottom-up.

Futhermore, the binned distraction effect RT analyses resulted in a Condition × Bin interaction, indicating that the fastest responses (those in the 20% – 40% percentiles) showed less distraction effect in the *never* condition compared to the *sometimes* condition, but an equivalent effect in slower responses. Thus, in the context of our task, while the distractor consistently slowed down performance across all response durations (as evident in positive distraction effect values in Figure 5), top-down control over distraction operates predominately at the most efficient (i.e., fastest) processing stage. Importantly, the age groups were applying top-down control in a similar manner, which (to our knowledge) is the first demonstration that the age-related preservation of top-down control is evident even in its distribution across the RT spectrum. This result cannot be explained as an artifact of low statistical sensitivity, as power analyses (Cohen, 1988) indicated that, in the present design, with 24 participants per group, there was .92 power to detect a significant Age Group × Condition interaction (alpha = .05) when the effect size is .25 or greater.

The lack of group differences in the time course of the distraction effect was unexpected, given that an earlier study that examined group differences in stimulus-response spatial compatibility effects in the Simon task found the effect was transient for younger adults but sustained for older adults (Castel, Chasteen, Scialfa, & Pratt, 2003). Although the Simon task and our visual distraction task both require response inhibition, the tasks differ in performance complexity and may represent different inhibitory control components. Our task involves identification of both a shape singleton and the symbol located within it, with displays containing multiple nontarget items in a randomized arrangement. In comparison, inhibition in the Simon task is represented in simpler incompatibility of stimulus-response mappings using relatively sparse displays (cf. Lu & Proctor, 1995). The inhibitory control required in the Simon effect has been hypothesized as a two-step model, with a fast, transient component and a slow, sustained component (Wiegand & Wascher, 2005). In contrast, inhibitory control in our distraction visual search task is sustained across the time course, a response pattern shared by both age groups. This group similarity extends into the comparison of the *never* and *sometimes* time courses, as both age groups minimized distraction predominantly in the earliest (fastest) response bins of the *never* condition. While speculative, the strong similarity between older and younger adults in the effect of distraction across the RT distribution suggests that it is unlikely that older adults are using qualitatively different strategies relative to younger adults (Greenwood, 2007). Strategy differences would likely express themselves, if not in an overall distraction effect difference, then at least latently in the dynamics of the percentile bin effects.

Beyond age effects, our results also speak to the ongoing debate on the extent of top-down control to override bottom-up distraction. As detailed in the introduction, the literature is unresolved as to whether top-down control effectively attenuates attentional capture (Leber & Egeth, 2006) or whether bottom-up distraction effects remain constant despite top-down control (Theeuwes et al., 2006). Our results provide qualified support that top-down control can mitigate the distracting effects of bottom-up singleton distraction, in that participants were able to minimize the effect of the non-target color singleton in the *never* condition compared to the *sometimes* condition. The reduction of distraction in the *never* condition was nearly complete, with a *z*RT distraction effect (distraction present – no-distraction) of only .04 units. This is comparable to the results of Leber and Egeth (2006), in which RTs in the feature search group showed only a slight increase when nontarget color singletons were present. Note that search times in their task were highly efficient (i.e., evidenced no positive search slope across display size) whereas our task was somewhat more difficult, with RT slopes of ~9 ms per item for younger adults and ~14 ms per item for older adults. Theeuwes (2004) has noted that in less efficient visual searches, such as ours, attentional capture by a distracting singleton is less likely, as the positive search slope is indicative of a reduced attentional window. Thus, our results are not entirely inconsistent with Theeuwes' attentional window account. Nevertheless, the primary finding of the reduction of distraction effect from the *sometimes* to the *never* conditions suggests that participants were able to adopt a top-down search strategy, effectively operating within the predictions of a feature search mode (Bacon & Egeth, 1994; Leber & Egeth, 2006).

A surprising result from our task was the slowdown in performance when the color singleton was also the target. These trials resulted in a sharp spike in *z*RT, as evident in Figure 5 (position 0) that continued to negatively affect the consequent trial (position +1). This was unexpected, as several visual search studies have suggested that the added bottom-up saliency of color to the target should either facilitate detection (Proulx, 2007) or at least impose no debilitation (de Fockert, Rees, Frith, & Lavie, 2004). Perhaps the most likely explanation for this *z*RT rise is that target identification in our task requires two separate cognitive stages. Participants first had to identify the shape singleton, and second to discriminate the symbol (= or +) within it. Color may have benefited the first stage (shape identification) but not the second stage (symbol discrimination), or even detracted attentional resources away from the second stage. Another possibility is that participants have conflicting assignments for the color singleton during the sometimes condition, when it is typically a distractor (thus, it should be ignored) but sometimes a target (thereby reassigned as target). Previous research has shown that such assignment mappings are tuned on a trial-by-trial basis, and that intertrial reassignments can carry over to affect consequent trials (Olivers & Humphreys, 2003). Future research should assess this possibility more directly, as our novel discovery of increased *z*RTs for color singleton target trials (and their carry-over effect) suggests that increased bottom-up saliency of targets may facilitate between-item but not within-item discriminations.

Conclusion

We examined performance differences in older and younger adults in a distraction visual search task, and found strong evidence that older adults have preserved top-down control to minimize the effect of distracting color singletons. Analyses of raw RT revealed that the color singleton distractor affected performance negatively for both age groups, as compared to trials without color distractors. Older adults were slower than younger adults and exhibited stronger effects of distraction from the irrelevant color singleton. However, after accounting for generalized slowing through the *z*-score transform of the dataset, Age Group did not significantly interact with Condition (*never*, *sometimes*), indicating that the two age groups were equivalent in utilizing the top-down control evident in the *never* condition (compared to the *sometimes* condition) to speed their performance. Furthermore, the transformed dataset yielded no Age Group × Distraction (*present*, *absent*) interaction, indicating that compared to younger adults, the older adults exhibited a similar slowdown in *z*RT due to the distraction of color singleton nontargets. These broad findings of age group equivalence of distraction were corroborated using an analysis technique in which the distraction effect was binned by percentile along the RT distribution. These analyses revealed that top-down control over distraction was not affected by aging, as both older and younger adults evidenced a distraction reduction in the fastest responses in the *never* condition compared to the *sometimes* condition, but equivalent distraction effect in the slower responses.

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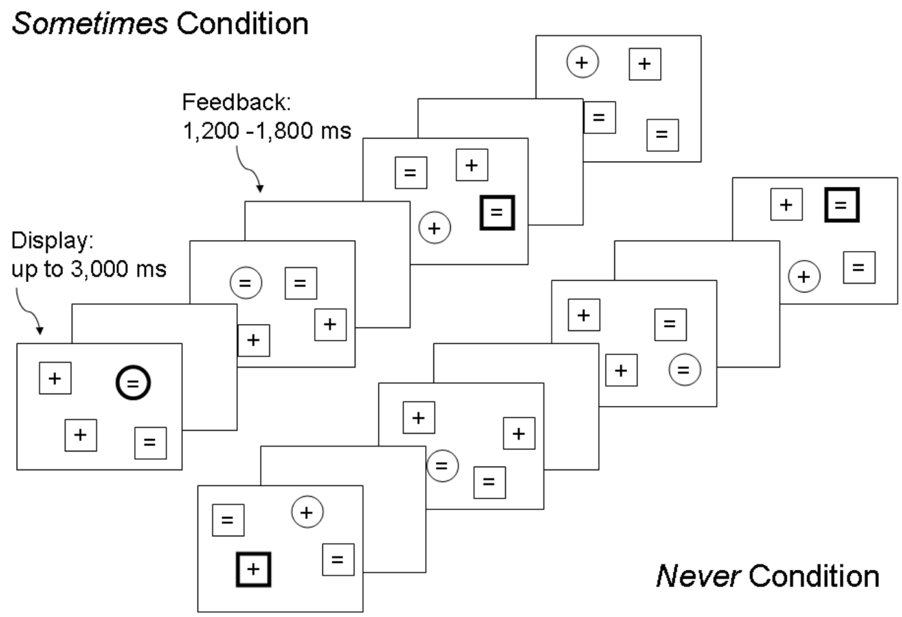

Figure 1.
Illustration of trials in both the *sometimes* and *never* conditions (not to scale). Participants responded to the symbol (+ or =) within the shape singleton (circle). Display items were presented as green outline shapes against a black background, except for the red color singleton, illustrated in the figure by the bold outline shape. In the feedback interval, the screen was blank for correct responses but presented the word “incorrect” on error trials.

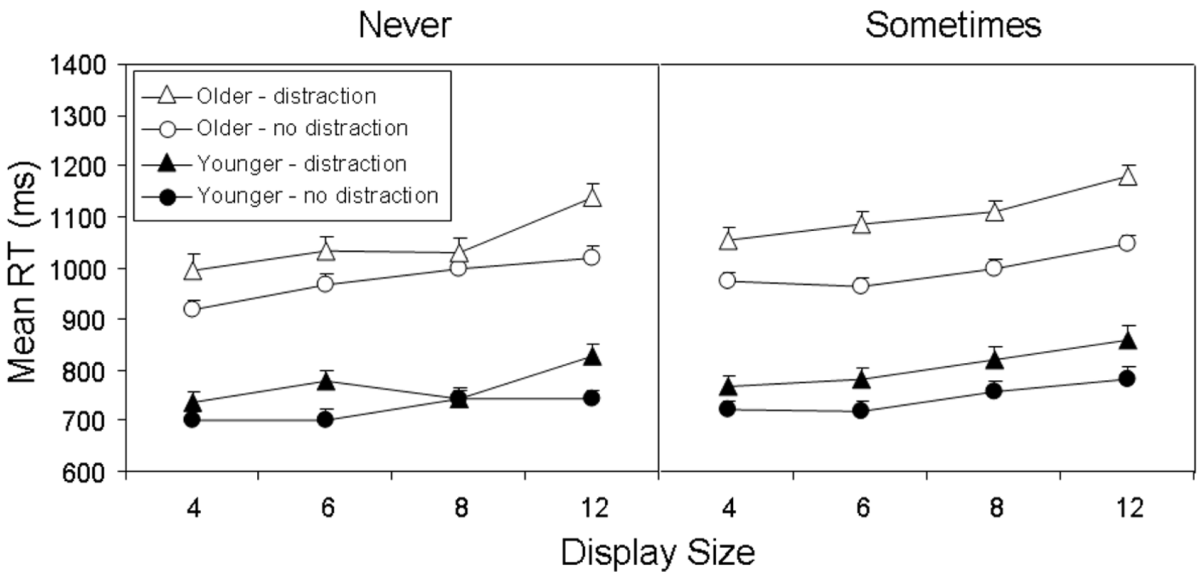

Figure 2.
Mean reaction time (RT) as a function of age group, condition, and display size. Error bars represent standard errors of the mean.

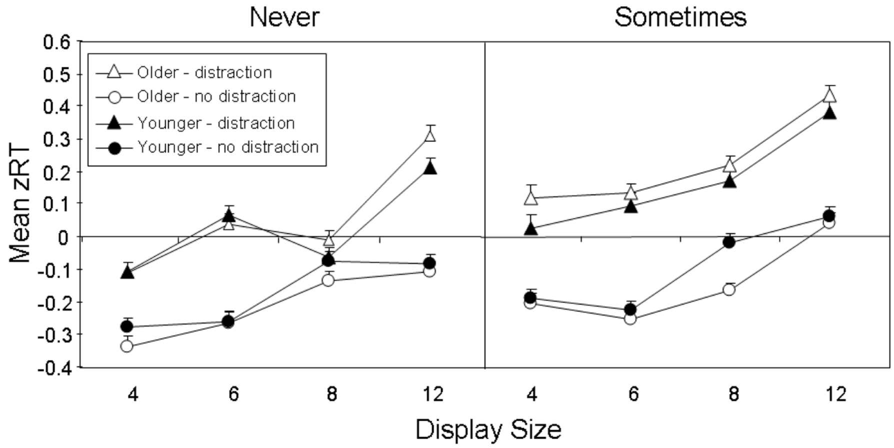

Figure 3.
Standardized reaction time (zRT) as a function of age group, condition, and display size. Error bars represent standard errors of the mean. The values above the zero point represent slower performance, and those below the zero point represent faster performance. Age group interactions disappeared after the *z*-score transform.

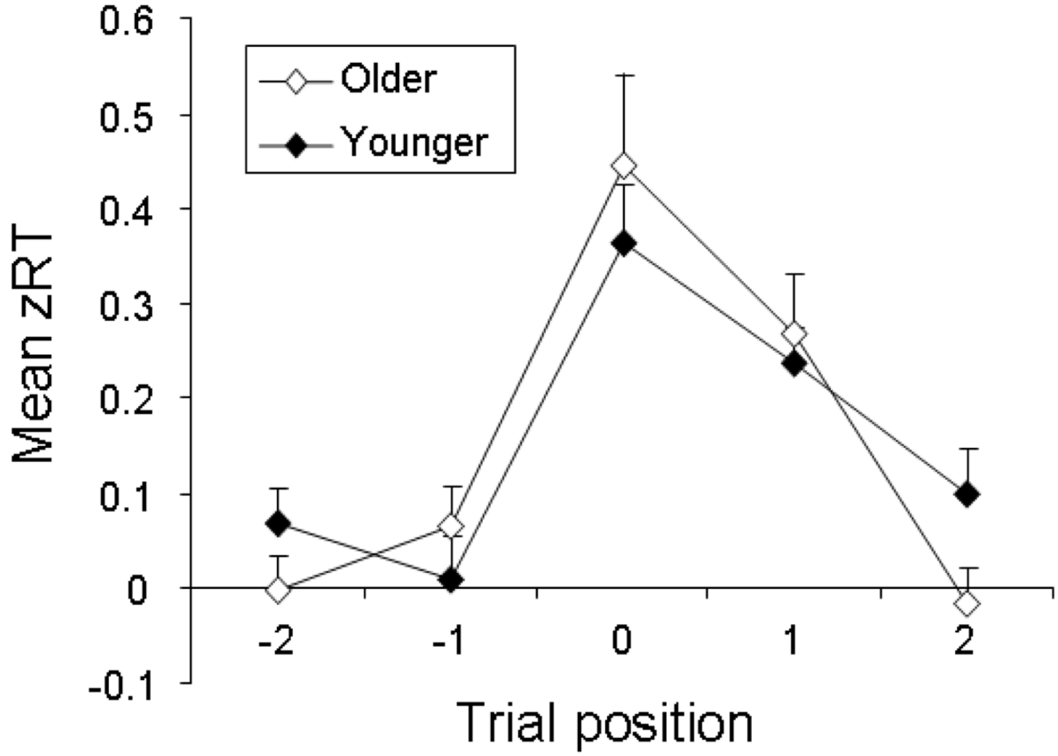

Figure 4.
Standardized reaction time (*z*RT) in the *sometimes* condition as a function of age group and trial position relative to the color singleton target (position 0). Error bars represent standard errors of the mean. There was a sharp slowdown in performance for color singleton targets that extended into the subsequent trial.

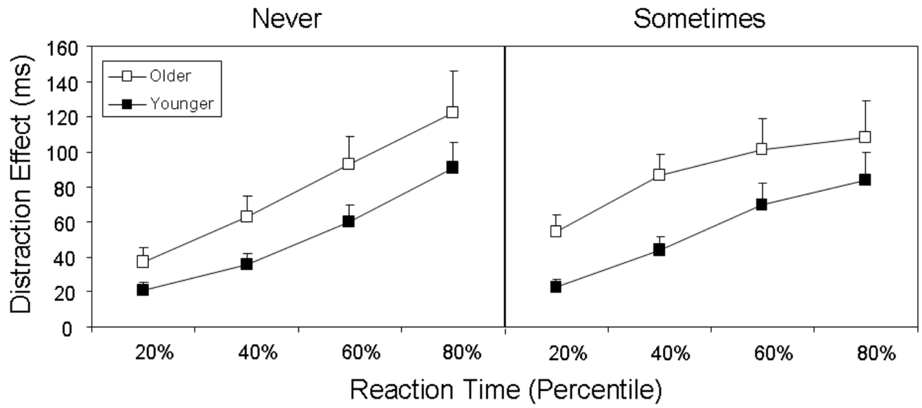

Figure 5.
Distraction effect (distraction present RT – no-distraction RT) as a function of age group, condition and reaction time percentile. Error bars represent standard errors of the mean. For both age groups, distraction was sustained across the RT distribution, with a reduction of the distraction effect in the earliest bins (20% & 40%) evident when comparing the *never* and *sometimes* conditions.

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Table 1

Participant Characteristics by Age Group

	M		*SD*	
	Younger	**Older**	**Younger**	**Older**
Age (years)	21.08_a	68.29_b	3.01	6.13
Education	14.25_a	16.46_b	1.45	2.54
Vocabulary	63.17_a	64.25_a	3.67	3.42
Visual Acuity	-0.14_a	-0.04_b	0.09	0.11
Color Vision	13.67_a	13.54_a	0.64	0.66

Note. n = 24 per age group. Vocabulary = raw score (maximum of 70) on the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); Visual Acuity = Landolt C acuity measure from Freiburg Visual Acuity and Contrast Test (FRACT) (Bach, 1996), with a logMAR of 0 equivalent to 20/20 acuity and lower values indicating better acuity. Color Vision = score (out of 14) on the Dvorine color plates (Dvorine, 1963). Means in the same row that do not share subscripts differ by t-test at $p < .05$.