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Cale White, Dana Wheatley, Olga Konwisorz, Charles T. Scialfa

Department of Psychology, University of Calgary,

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Age Differences in the Distractor-Ratio Effect as a Function of Contrast Level

CALE WHITE, DANA WHEATLEY, OLGA KONWISORZ AND CHARLES T. SCIALFA
Department of Psychology, University of Calgary

ABSTRACT

Latencies (RT) and eye movement measures were used to examine the effects of age and contrast on the distractor-ratio effect (DRE) in visual search. Younger and older adults performed a contrast × orientation conjunction search task where the ratios of white to black distractors and luminance contrast levels were varied. The distractor-ratio manipulation had similar effects for older and younger adults on both RT and the number of fixations required to find the target. Both measures were largely independent of distractor ratio on target-present trials, while both RTs and the fixation number increased with the number of items sharing the target’s contrast polarity on target-absent trials. A more detailed analysis of eye movements suggested that younger adults were a bit more adept at attending to the smaller set of distractors, which presumably facilitated both overt and covert search. Generalized slowing can account for the age differences in RT, but the fixation number data speak to another mechanism, perhaps increased cautiousness on the part of the elderly when signal strength is low.

Visual search is the process through which task-relevant objects are located, detected or identified (Scialfa et al., 1998). People engage in this process often, as when they are trying to find a button on the television’s remote control or identify a right-of-way traffic sign. At times, search can be carried out quickly and easily, with a minimum of cognitive effort. At other times, a search is difficult, time-consuming, and error-prone. There are a variety of stimulus-based factors (e.g., display contrast and density) and top-down factors (e.g., knowledge of target probability and location) that influence search performance, some of which show a decline in older adults and render a search more difficult for them. The present study examines one such factor, called the distractor-ratio effect (DRE), in which performance is influenced by the proportion of distractors sharing each target feature (Shen et al., 2000).
THE DISTRACTOR-RATIO EFFECT

In many studies of visual search where each distractor shares some features with the target, the ratio of distractor types is approximately 1:1 and remains constant over changes in the number of distractors. When these conditions hold, there is often a linear relation between performance and distractor number that is referred to as the display size effect (Plude & Doussard-Roosevelt; 1990; Ho et al., 2003; Treisman & Gormican, 1988; Wolfe et al., 1989). However, when the ratio of different distractor types is extreme, improvements in search efficiency have been reported. For example, Egeth et al. (1984) held the number of distractors sharing the target color at a constant low number while they examined a color $\times$ form conjunction search. They found that RT was independent of distractor number. To explain this they suggested that figure-ground segregation is facilitated when there is an extreme distractor ratio and that objects in the ground are rejected in parallel.

More recently, Shen et al. (2000) studied the DRE in a color (red or green) and shape (O or X) conjunction search task. The ratio of red to green distractors varied between 3:45 and 45:3. On target-present trials, RT was not strongly influenced by the distractor ratio. In contrast, on target-absent trials there was a quadratic relation between distractor ratio and response latency, with performance being best at extreme ratios. They also measured eye movements and found a similar pattern in the number of fixations prior to making a response. An even more interesting analysis of the eye movement data came from the examination of saccadic selectivity, operationalized as the probability of fixating an object in relation to the features it shares with the target (Ho & Scialfa, 2002; Ho, Siakaluk, & Scialfa, 2003; Scialfa, et al., 2000). They found that participants were more likely to direct fixations to distractors sharing the target color when there were only a few of them, but switched their gaze to distractors of a similar shape when the number of same-color distractors became large and hence the number of same shape distractors was small.

THEORETICAL ACCOUNTS OF THE DRE

There have been several explanations proposed for the DRE. Like Egeth et al. (1984), Zohary and Hochstein’s (1988) subset-switching hypothesis asserts that observers preattentively separate the display into figure and ground. When the ratio is near 1:1, participants choose the feature that is more salient, typically color, and search through those items serially. When ratios become extreme, the items with the infrequent target feature are perceived as the figure and are processed serially. All other items are viewed as ground and rejected in parallel. This would explain the parabolic function relating performance to distractor ratio, provided that observers can quickly switch the subset they search based on figure-ground segregation.
Poisson and Wilkinson (1992) argue that the subset-switching hypothesis does not explain the different performance patterns in target-present and target-absent trials. If observers were able to switch strategy from trial to trial, the target-absent functions would be steeper than the target-present functions, but would mirror their shape. In addition, they point out that subset switching cannot account for the common finding that target-absent RT functions are strongly skewed toward a target feature on one dimension (e.g., color). Poisson and Wilkinson’s (1992) distractor grouping account proposes that although the ratio of distractors influences processing, participants do not switch strategies from trial to trial. Instead, they assert that for target-absent trials, observers always select one dimension for search and that at extreme ratios, they can reject dissimilar distractors en masse. They admit, however, that this explanation is inadequate to explain the differences between target-present and target-absent trials and instead suggest that pop-out supercedes grouping when the target is present.

Recently, many phenomena in visual search have found a reasonable accounting in the Guided Search Model (GSM) of Wolfe and his colleagues (Cave & Wolfe, 1990; Wolfe et al., 1989). Under this view, a fast, parallel stage produces element-wise activation levels that are then used in descending order to guide the search. This stage has two components. Bottom-up activation is determined by an item’s feature-based contrast with other elements in the display. Top-down activation is determined by the similarity of the item to the target representation that is held in working memory. The search ends on target-present trials when the target is found. On target-absent trials, the search is terminated by a time or activation threshold determined from the average of target-present trials. A variable noise component is built into the model, yielding imperfect guidance. Otherwise, the search would always be independent of factors such as distractor number, similarity, etc.

The GSM can be used to account for the DRE in the following way. On target-present trials, when the target differs from distractors on one salient dimension, target activation is sufficiently great so that performance is largely independent of display characteristics like distractor number (Ho et al., 2003; Wolfe, 1998; Wolfe, et al., 1989). In fact, adding distractors can increase the bottom-up component for the target so that RTs decrease with display size. On target-absent trials, at extreme distractor ratios, the smaller set of items receives greater bottom-up activation and is searched first, with the consequent reduction in RT and fixation number. Because the top-down weight given to each feature is fast and flexible (Scialfa et al., 2004), observers can change the features they attend first and thus search the smaller set of items. Furthermore, because stimuli need not be equally salient on all dimensions, these processes might be more effective at one end of the spectrum of distractor ratios, as has been reported by both Poisson and Wilkinson ((1992) and Shen et al. (2000). Finally, when the distractors are present in
approximately equal number, even a search of a subset of items involves 50% of the display items, resulting in the elevated RTs at that point in the distractor ratio function.

Attentional allocation in a search is based generally on feature salience. For example, color and luminance contrast are particularly salient features and it has been repeatedly found that observers chose them over shape, orientation, and other dimensions to facilitate search (Scialfa & Joffe, 1998; Ho et al., 2003; Williams & Reingold, 2001). Relatedly, Williams and Reingold (2001) have reported that one can reduce or enhance the use of particular features by changing their salience. Thus, it is possible that the DRE can be reduced when feature salience is minimal. One of the purposes of the present study is to determine if this is the case. We chose to manipulate salience via changes in luminance contrast and we expected that the DR effect would be less pronounced in the low luminance contrast condition because, in this condition, it is more difficult to discern element features and thus more difficult to segregate the display and allocate attention based on those features.

AGING AND VISUAL SEARCH

The performance of many tasks suffers as we grow older and this is certainly true of visual search (Rabbitt, 1965; Madden & Whiting, 2004). Age differences in a search are relatively small in feature search but are larger in conjunction search and when target-distractor similarity is great (Ho & Scialfa, 2002; Plude & Doussard-Roosevelt, 1990; Scialfa et al., 1998; Scialfa et al., 2000). These age differences have been attributed to numerous mechanisms, including an inability to ignore irrelevant information (Rabbitt, 1965), a deficit in the allocation of selective attention (Rogers & Fiske, 1991), problems with stimulus localization (Plude & Hoyer, 1985), and generalized slowing (Scialfa et al., 1998).

However, many manipulations that reduce search rates through more efficient allocation of attentional resources work equally well for younger and older adults. These include cues that provide advance information about target color (Madden et al., 1999) or location (Plude & Hoyer, 1985) and some instantiations of consistent mapping during training (Scialfa et al., 2000; Ho & Scialfa, 2002). As well, in a series of search studies that included eye movement measures, Scialfa and colleagues have shown that the elderly are quite capable of optimizing a search by attending largely to objects that share salient target features.

Of direct relevance to this study, Plude and Doussard-Roosevelt (1990) compared younger and older adults in shape × color conjunction search. In one condition, the two types of distractors were kept in 1:1 ratio. Here RT increased with the number of items in the display and to a greater degree for older adults. This finding was interpreted as a reflection of age deficits in selective attention required to serially search items in the display. In another
condition, a replication of Egeth et al. (1984), the number of distractors sharing one target feature was held constant. Display size was varied and so the distractor ratios changed with display size. For younger and older adults, RT was independent of display size, suggesting that both groups selected the smaller group to search first. Plude and Doussard-Roosevelt argued, therefore, that the parallel processing allowing for subset selection (or \textit{en masse} rejection of the larger distractor set) was age-invariant. Because Plude and Doussard-Roosevelt did not include a large and symmetric range of distractor ratios, there data did not reveal a DRE for either age group.

Accounts of the DRE (Poisson & Wilkinson, 1992; Wolfe, 1998; Zohary & Hochstein, 1988) assert that it arises because observers can attend selectively, quickly, and with relatively little attentional effort to a subset of the items in the display and that this is particularly advantageous on target-absent trials at extreme distractor ratios. If older adults were not as capable of this form of selective attention, then we would expect them to exhibit a reduced DRE. Furthermore, this may be particularly true under low salience conditions that are difficult for older adults (Scialfa et al., 1998). If, on the other hand, this type of attentional allocation is age-invariant, then age differences in search should be largely determined by generalized slowing alone (see Lawrence et al., 1998; Scialfa et al., 1998; Scialfa & Joffe, 1997).

In this study the participants were asked to detect a white line oriented 45 deg to the right among a display of black lines orientated 45 deg right and white lines 45 deg left. The display size remained constant at 64 items with the white-to-black ratio varying along 5 points between 8:56 and 56:8. The contrast between the background and display elements was also varied. In addition to generalized slowing, we expected that the DRE would be observed in the reaction time data of both younger and older adults, but only in equal magnitude if older adults were able to selectively attend to the smaller subset of distractors. We also expected that low contrast displays would be more difficult to search, produce a smaller DRE, and be more likely to reveal age-related search deficits. Following recent eye movement studies, we also expected these patterns to be mirrored in the frequency with which observers fixated items in the displays. Finally, we anticipated that eye movements would show a bias to fixate items comprising the smaller subset. The extant literature (e.g., Ho & Scialfa, 2002; Scialfa et al., 2000) is not clear about whether to expect age deficits in this selection factor.

**METHODS**

**Participants**

Twelve younger adults ($M = 24.08$ years, $SD = 2.75$ years) and 12 older adults ($M = 64.33$ years, $SD = 8.73$ years) were recruited from the
Calgary, Alberta, Canada community to participate in the study. All participants received $5 Canadian after each session, and if they completed both sessions they received an additional $10 Canadian as a bonus. Both groups were relatively well educated but there was a significant difference in education ($p = .033$) between younger adults ($M = 15.58$ years, $SD = 2.31$ years) and older adults ($M = 13.73$ years, $SD = 3.20$ years).

All participants indicated that they were in good overall physical and visual health. None had been hospitalized within the last year, nor were they currently under a physician’s care for a serious medical condition. Corrected acuity (Burton 100 TLS, Grove City, OH) was measured at a distance of 60 cm using postscript generated Landolt Cs with eight targets for each level of minimum angle of resolution, which varied in steps of approximately 0.5 log units. All participants had corrected acuity of 20/20 or better and there was no difference between younger adults ($M = 1.24$, $SD = .18$), and older adults ($M = 1.26$, $SD = .23$). Contrast sensitivity was also measured using the Vistech VCTS Contrast Test System. While younger adults had better contrast sensitivity at most spatial frequencies, all participants were within normal limits for their ages. Intraocular pressure (Reichert NCT II, Depew, NY) was also within normal limits for all participants.

**Apparatus**

The conjunction search displays were created and presented on the Eye-gaze Development System (EDS) provided by LC Technologies, Inc. (Fairfax, VA). Stimuli were shown on a 15-inch Sony Trinitron Multiscan CPG-100 GS monitor. The resolution on the monitor was set at $640 \times 480$ pixels and the refresh rate was 60 Hz. A 486-computer platform was used to run the EDS, which measured eye movements using the pupil/corneal reflection technique. An LED placed underneath the monitor flooded the eye with a low-level infrared light (880 nm). A Sanyo CCD high-speed, infrared camera collected the infrared reflections at a rate of 60 Hz. Recalibration occurred following each block of 50 trials. To ensure the same eye location relative to the monitor, participants rested their forehead and chin against a head restraint that was secured at a fixed distance of 60 cm. This was vertically adjustable by 14 cm to allow participants to sit in a comfortable position.

**Stimuli**

The search display consisted of one target and two types of distractors arranged in an $8 \times 8$ matrix, subtending 11.8 deg on each side. The target was defined as a white line tilted 45° to the right, while the distractors were either white lines tilted 45° to the left or black lines tilted 45° to the right. Thus, the target shared a feature with each of the distractors. In the high contrast condition, the stimuli were set at maximum contrast (white = 79.09 cd/m²; black = 6.24 cd/m²) against a gray background (43.33 cd/m²). In the
low-contrast condition, the contrast was reduced by about one-half, such that the white lines were now set at 61.21 cd/m² and the black lines were set at 24.78 cd/m² against the same background. Each line was approximately 6.3 mm × 0.84 mm, which at the test distance subtended 0.60 deg in length and 0.08 deg in width. The stimuli were restricted to an active display of 131.88 mm (12.40 deg) with minimal separation for stimuli of 4.2 mm (0.40 deg). Stimuli were “jittered” both horizontally and vertically, which resulted in differing distances between items within each display.

**Design**

The study consisted of two sessions each lasting approximately 1 hour with a 2-to-5-day separation between them. Each session consisted of 6 blocks of 50 trials for a total of 600 trials per person. To avoid practice effects, the first 20 trials for each session were discarded. Contrast level was blocked in sessions and the order of sessions was counterbalanced. The display size was kept constant at 64 items, but the ratio of white to black distractors was varied across trials. On target-absent trials, there were five different ratios of white and black distractors (8:56, 16:48, 32:32, 48:16, and 56:8), which were randomized with equal probability across all trials. On target-present trials, a randomly chosen distractor was replaced with the target. Target presence was randomized with equal probability across all displays.

**Procedure**

Each trial began with a black fixation cross, placed in the center of the gray background. The participants were instructed to fixate the cross at the beginning of each trial. They had to press a key to initiate the onset of the search screen. The fixation screen disappeared after a randomly determined 50, 100, or 150 ms and, immediately after the offset of the fixation screen, the search display was presented. The participants were given 5 s to search the display and indicate if the target was present or absent by pressing the corresponding key (J = target present; F = target absent). Feedback regarding trial performance was given following each response; a plus sign indicated a correct response and a minus sign indicated an incorrect response. If no response was indicated in the allotted 5 s (a very rare occurrence), a question mark was displayed.

**RESULTS**

The dependent measures reported here include error rates, RT, fixation number, and the selection factor, to be explained below. A trial was discarded if the EDS could not sample eye position accurately. A response was counted as an error if the observer pressed the wrong key for the trial and the error count did not include trials that ended without a response. RTs, fixation
number, and the selection factor was based only on those trials ending in a correct response. Mean RT for an individual excluded trials that were more than +/- 2 SDs from the person’s mean for that condition. A fixation was counted whenever two successive samples of eye position were within the same 11-pixel window and samples continued to be counted as belonging to that fixation until a sample fell outside the 11-pixel window that was a moving average of the previously calculated fixation’s coordinates. The selection factor was calculated as the probability of landing closer to a white item than a black item and was determined on a fixation-by-fixation basis.

All dependent variables were analyzed using Age (2) × Presence (2) × Contrast (2) × Ratio (5) mixed-model analyses of variance (ANOVAs). Only results found to be significant at an alpha level of .05 are reported. Tests involving a repeated factor used a Geisser-Greenhouse correction for violations of the ANOVA’s assumptions (see Maxwell & Delaney, 2004). Any planned follow-up tests are carried out with a Bonferroni adjustment to the alpha levels.

Error Rates

Although older adults had a greater number of errors than younger adults, errors were uncommon, averaging less than 5%. Main effects of presence $F(1, 22) = 77.33, p < .001, \eta^2_p = .78$ and ratio $F(4, 88) = 11.66, p < .001, \eta^2_p = .35$ were found, a reflection of the fact that errors were more often misses than false alarms and that they were more common in the 32:32 condition. There was the significant presence × age interaction, $F(1, 22) = 6.24, p = .02, \eta^2_p = .22$. A difference between younger and older adults’ error rates was observed only in the target-present condition. The interaction arose because older participants made about 1.5 percent more mistakes than young participants on target-present trials while there were no differences on target-absent trials. We did not consider this to be important because error rates for both groups were so low and there were no other effects involving age. Also significant were the contrast × ratio, $F(4, 22) = 2.93, p = .025, \eta^2_p = .18$, and presence × ratio interactions, $F(4, 88) = 10.64, p < .001, \eta^2_p = .33$. The former effect arose because more errors were made in the low contrast condition when the distractor ratio was close to 1:1. The latter effect occurred because the error rate was greatest on target-present trials at more balanced distractor ratios.

Reaction Times

Mean RT is shown as a function of distractor ratio, presence, and contrast in Figure 1. Older adults were generally slower than their younger counterparts. As expected, the DRE was observed at both contrast levels and within both age groups in the target-absent condition, but not in the target-present condition.
The ANOVA revealed a main effect of age, $F(1, 22) = 366.57, p < .001, \eta_p^2 = .35$, distractor ratio, $F(4, 88) = 44.76, p < .001, \eta_p^2 = .67$, presence, $F(1, 22) = 163.84, p < .001, \eta_p^2 = .88$, contrast, $(1, 22) = 27.09, p < .001, \eta_p^2 = .55$. Importantly, the quadratic component to the ratio effect was significant. Overall, participants were quicker to respond when the target was present, when it was of a higher contrast, and when there were a smaller number of white items. A pair of two-way interactions was found to be significant. The contrast $\times$ presence effect, $F(1, 22) = 15.79, p = .001, \eta_p^2 = .42$, showed that the discrepancy between high and low contrast increased when the target was absent. The presence $\times$ ratio interaction, $F(4, 88) = 86.47, p < .001, \eta_p^2 = .80$ arose because the distractor ratio influenced RT primarily in the target-absent condition. These results mirror the findings by Shen et al. (2000).
Although the more dramatic effect of distractor ratio on RTs clearly occurred on target-absent trials, Figure 1 shows that response latencies tended to be inversely related to the distractor ratio on target-present trials. Collapsed across age, the RT difference between the 8:56 and 56:8 ratios was 257 ms on high-contrast displays and 295 ms in low-contrast displays. In both cases, a one-way ANOVA of the ratio effect, collapsing across age revealed a systematic reduction in RTs when the number of white items increased, ($p$ < .001).

**Fixation Frequency**

Mean fixation frequency is shown as a function of distractor ratio, presence, and contrast in Figure 2. The trends observed are similar to those seen in the RT data. Older adults made more eye movements than the young

![Figure 2. Fixation frequency for target-present (TP) and target-absent (TA) trials as a function of distractor ratio and contrast. (A) younger adults (B) older adults.](image-url)
and the DRE was seen in both contrast conditions, but was confined largely to target-absent trials.

All main effects were significant showing that in addition to older adults fixating more than young adults, $F(1, 22) = 434.35$, $p < .001$, $\eta^2_p = .32$, more fixations were made when the target was absent, $F(1, 22) = 143.60$, $p < .001$, $\eta^2_p = .87$, contrast was low, $F(1, 22) = 6.69$, $p = .017$, $\eta^2_p = .23$, and as the ratio approached 1:1, $F(4, 88) = 41.60$, $p < .001$, $\eta^2_p = .65$. As with the RT data, the quadratic component to the DRE was significant. The two-way interaction of most interest was the presence $\times$ ratio effect, $F(4, 88) = 101.11$, $p < .001$, $\eta^2_p = .82$ that replicates findings by Shen et al. (2000) in that the DRE was seen largely on target-absent trials. The presence $\times$ age interaction, $F(1, 22) = 71.21$, $p = .048$, $\eta^2_p = .17$, showed that older adults made a relatively greater number of fixations than younger adults in the target-absent condition compared to the target-present condition. The interaction of contrast and presence $F(1, 22) = 13.10$, $p = .002$, $\eta^2_p = .37$ demonstrated that more fixations were made for target-absent than target-present trials and that this difference was more prevalent when contrast was low. The only three-way interaction observed was the contrast $\times$ presence $\times$ ratio effect, $F(4, 88) = 5.39$, $p = .001$, $\eta^2_p = .20$. On target-present trials, fixation number was slightly lower when the displays contained a large number of white items, but this did not vary across contrast levels. In comparison, on target-absent trials, the DRE was seen at both contrast levels but the mean number of fixations was greater in low-contrast displays.

As with the reaction time data, we analyzed the DRE for target-present trials, collapsing across age, to see if the apparent decline in overt search (see Figure 2) was more than expected by chance alone. For both high-contrast and low-contrast displays, the effect was significant ($ps < .001$), reflecting a decline of about 1 fixation on high-contrast trials and 1.25 fixations on low-contrast trials.

### Selection Factor

Following Scialfa et al. (2000), the selection factor was operationalized as the probability with which observers fixated white objects. The average selection factor is plotted as a function of distractor ratio and contrast in Figure 3. It can be seen that for both age groups, the probability of fixating white objects is a monotonic function of the number of white objects in the display. This should come as no surprise for purely stochastic reasons. What is more interesting is that both age groups “over fixate” at low distractor ratios. Younger adults exhibited a relatively larger selection factor on target-absent trials, as well.

Consistent with these trends, the main effect of distractor ratio was significant, $F(4, 88) = 280.70$, $p < .001$, $\eta^2_p = .93$. A pair of two-way interactions were also obtained. The age $\times$ ratio effect, $F(4, 88) = 9.55$, $p < .001$,...
η^2_p = .30, indicated that older adults selected white items less often than young adults when there were few white items in the display (e.g. the 8:56 ratio), while age differences diminished at higher distractor ratios. The other interaction of presence × ratio, \( F(4, 88) = 4.91, p = .018, \eta^2_p = .18 \) arose because observers selected white stimuli more often when the target was absent. This effect must be qualified, however, by the significant presence × ratio × age interaction, \( F(4, 88) = 6.69, p = .006, \eta^2_p = .23 \). This reflects the observation that younger adults were most likely to fixate white items when the target was absent and the distractor ratio was low. Older adults had a similar response to changing distractor ratios, but it was of equal magnitude for both target-present and target-absent trials.

**Generalized Slowing Analysis**

The linear function based on younger adults’ RTs accounted for more than 97% of the variance in older adults RTs across the 20 conditions tested. The estimated slowing effect (~1.4) fell comfortably within the range anticipated by a general slowing hypothesis. Following Scialfa and Joffe (1997), a
similar Brinley analysis was carried out on the fixation number data. A linear function with a slope of 1.34 accounted for more than 95% of the older adults’ data. Thus, like the RT data, the fixation data of older adults are related in a simple way to those of younger adults and the slopes for the RT and fixation number analyses are almost identical. This finding, replicating Scialfa and Joffe (1997) cannot be explained by generalized slowing alone (Lawrence et al., 1998; Salthouse, 1996). Such an account might posit that more eye movements are required by older adults, who lose information from Visual Short-Term Memory (VSTM) due to slowing. However, this would imply poorer memory for objects previously searched and Boot et al. (2004) have reported, in fact, that their location memory is superior to young observers.

**DISCUSSION**

Both RT and fixation number data replicate Shen et al’s (2000) findings of a nonlinear relation between performance and distractor ratio that surfaced primarily in target-absent trials. Our results are very similar to those of Poisson and Wilkinson (1992) and Zohary and Hochstein (1988) in that performance is worse when both distractor types are equally likely and that the improvement in performance seen at extreme distractor ratios is not symmetric, but more pronounced when there are relatively few white items in the display. Reduction of luminance contrast had the expected effect of impairing performance, but this effect was also restricted largely to displays in which there was no target. The selection factor analysis demonstrated that observers showed a preference to fixate white items and that this preference departed from chance expectations primarily when white items formed the smaller group in the display.

**Theoretical Accounts of the DRE**

There are three primary findings in the present work that are in need of explanation: First is the asymmetric inverted-U function in RTs and fixation number on target-absent trials; second is the inverse relation of RTs and fixation number to the distractor ratio on target-present trials; finally, there are the selection factor data showing that there is a bias to select white items when there are few such items in the display and that this bias does not shift to the orientation dimension when there are many white items in the display.

The subset-switching hypothesis (Zohary & Hochstein, 1988) could account for the relatively fast RTs involving a small number of eye movements when there are few white items in the display. However, as has been pointed out by others (e.g., Poisson & Wilkinson (1992)), this account has difficulty explaining the discrepancy between target-present and target-absent trials. In addition, our data fail to show the symmetric decline in RTs and fixation number at both distractor ratio extremes. Finally, the selection
factor data do not indicate that observers switch to a search by orientation, as would be predicted when the number of white items is large and thus the objects oriented to the right form the smaller, more easily searched set. The *distractor grouping account* (Poisson & Wilkinson, 1992) also faces challenges in the present data because *en masse* rejection of distractors should work equally well at both ends of the distractor ratio continuum.

The Guided Search Model (Wolfe, 1998) can give a reasonable account of our results. In this view, observers searched through the set of white items, regardless of the number of items in that set, a top-down influence on activation that is seen most clearly in the selection factor data. On target-present trials, the inverse relation between performance and distractor ratio can be explained because when more of the items are white, the displays become like feature search displays and pop-out based on orientation occurs. On target-absent trials, however, increasing the number of white items increases the number of items that must be searched before the decision of target absence can be made. Thus, a nonsymmetric target-present function would be expected where, as is the case here, RTs and fixation number increase and then stabilize when the displays contain a large number of white items.

**Aging and Visual Search**

In most ways, the data of older adults mirror those of their younger counterparts and suggest that the mechanisms underlying the DRE are age-invariant. This was true even for the manipulation of contrast, which we expected could have a larger effect on the elderly because reduced salience is more problematic for the elderly (Scialfa, Esau, & Joffe, 1998). As such, the study adds to a growing database indicating that when attentional allocation can be based on a small number of salient features, negligible age differences are observed (Madden, Gottlob, & Allen, 1999; Scialfa et al., 2000). The Brinley analyses, despite some methodological criticisms (e.g., Perfect, 1994), suggest that the age differences that were observed were largely quantitative in nature. The finding from the fixation data that age differences are larger on target-absent trials is consistent with a more conservative criterion for terminating search. There are however, two findings regarding the age effects that need explication. The first is that on target-absent trials, older adults select white items less often than the young when there are few white items in the display. The second is that the Brinley analysis shows the same slope for fixation number and RT but only the latter is easily explained by the generalized slowing hypothesis (Lawrence et al., 1998; Salthouse, 1996).

The first observation may arise because the elderly have difficulty executing accurate saccades in the presence of nontargets (Scialfa et al., 1999). It may also occur because older adults made more eye movements on
target-absent trials and so landing on a black item is more likely to occur by chance alone. In any event, it is important to keep in mind that this is a small effect. Given the low number of fixations made by observers, the conditions where age differences in the selection factor are largest, these differences are produced by a difference of less than one eye movement per trial.

As mentioned above, the fact is that the age factor (∼1.4) is equivalent for RT and fixation number is problematic for the generalized slowing hypothesis. While one might make the argument that various time-based measures would show the same age effects within the same samples of people, fixation number is not a time-based effect. A more complicated version of the generalized slowing hypothesis could assert that age-related slowing in processes like the movement of attention and item inspection results in more information being lost from VSTM. Consequently, previously searched objects or regions must be revisited. On the surface, this seems plausible but it implies that information loss from VSTM has the same impact on RT as age-related slowing on constituent processes. This seems unlikely. Additionally, we have shown that older adults are no more likely to revisit previously searched objects. Scialfa et al., (1994) and Boot et al. (2004) demonstrated that older adults have better memory for object location in a search-like task.

**General Conclusions and Future Research**

The results of this study indicate that both younger and older adults make use of relative distractor frequencies to facilitate search performance. Specifically, on target-present trials both age groups were able to reduce overt and covert demands when there were larger numbers of white items in the displays. The selection factor data suggest that this occurred because overt attention was often directed to white items. On target-absent trials, this attention to white items conferred a search advantage when there were few white items in the scene. The RT and fixation number data, however, indicate that there were costs to this attentional bias when there were many white items that had to be searched. Given that a rapid switching to the smaller subset of black items would have minimized this cost, the data indicate a limitation to attentional selectivity and to both the subset switching and distractor grouping accounts of the DRE. Importantly, it appears that for the most part, older adults are capable of using distractor ratios to facilitate search. Thus, this research contributes to the gerontological literature by illustrating another aspect of attentional selectivity that seems to be age-invariant.

There are at least two ways in which the present study could be extended to examine cognitive aging. The first focuses on the observation that there was an age difference in bias toward white items at low distractor ratios. Specifically, older adults did not look with the same preference at
white items. It was argued above that both bottom-up and top-down processes could produce this bias. Top-down processes may not emerge in older adults because of the rapid changes in distractor ratio. A comparison of blocked and unblocked distractor ratios, perhaps with explicit instructions regarding optimal search strategies, would help resolve this issue. The second path for future research emphasizes the potential role of distractor ratios in more applied settings such as industrial inspection, air traffic control, and driving. For example, consider a driving simulation task where, depending on time of day, location, and other factors, distracting signage may be more or less prevalent. Can observers use this probabilistic information to limit processing to only those signs that are relevant to driving (e.g., regulatory and warning signs) and do older adults have more difficulty with selective attention in this context?

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