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# Age Differences in Feature Selection in Triple Conjunction Search

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**Younger and older participants were trained in a triple conjunction visual search task to examine age differences in the development of proficient performance. For the first 8 days, participants searched for a target defined by its contrast polarity, shape, and orientation. On Days 9 through 16, the target identity was switched to one defined by opposing feature values. On Day 17, the target was returned to the original feature values. Results indicated that, after training, younger adults reduced their display size effects more than elderly adults. Disruption occurred after the first but not after the second transfer. However, each time the target was switched, there were no age differences in disruption. Eye movement data suggest that older adults use a similar feature selection strategy as younger adults but may be more susceptible to distraction. The results are discussed in terms of current models of attention and search.**

LIKE many tasks, practice can improve the performance of visual search. Initially, complex search is slow and effortful, but with proper training, reaction times (RTs) and errors are considerably reduced and, in some cases, display size effects are eliminated. This transition from very slow, effortful, and serial searching to a fast, effortless, parallel search was initially examined and explicated in the classic work of Schneider and Shiffrin (1977). They argued that this transition from controlled to automatic processing was mediated by *associative learning* and *priority learning*. Associative learning refers to learning the appropriate relations involved in the task, such as the correct response when a target is present. Priority learning means that objects that share features with the target gain and objects that do not share target features lose attention–attraction strength with practice (Schneider, 1985). This differential assignment of attention–attraction strength among objects is the reason that the target will eventually appear to "pop out" and, thus, what was once a difficult search becomes automatic.

It has been suggested that priority learning suffers with age; that is, older adults have more difficulty assigning differential strength to targets and distractors. As a result, they do not develop automatic processing in visual search (Fisk & Rogers, 1991; Rogers & Fisk, 1991). This hypothesis is consistent with the frequently reported age deficit in asymptotic consistently mapped (CM) semantic category search; however, these results do not generalize to simpler visual search. For example, using a double-conjunction CM search for contrast polarity and orientation, Ho and Scialfa (2002) found that older adults performed as well as younger adults. They trained both age groups using a CM procedure and found that display size slopes for both groups were near zero, at least for target-present trials. In addition, older adults did not show any less disruption than their younger counterparts. What is most important is that, if it is the case that older adults suffer a priority-learning deficit, they should direct more eye movements toward objects that do not share target features. Instead, the results indicated that older and younger participants showed identical feature-based selection in their fixations.

The protocol used by Ho and Scialfa (2002) included not just one but several reversal sessions. They found that, the first time targets and distractors were reversed, participants showed disruption in RT and fixation number; however, subsequent reversals led to minimal or no disruption in performance, and this was the case for older and younger adults. Ho, Siakaluk, and Scialfa (2003) replicated this finding using triple-conjunction search and examining only younger adults. In fact, participants consistently used the correct target features to limit their search to only a few objects, and this strategy was then transferred to new target situations such that no disruption in RT was evident in later reversals.

Ho and colleagues argued that a pure strength theoretic approach could not account for this lack of disruption (Ho & Scialfa, 2002; Ho et al., 2003), and instead they proposed that a guided search (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989) or a rule-based model (Strayer & Kramer, 1994a, 1994b) may better explain the development of automaticity of visual search. Under both views, top-down knowledge of target features allows for the formation of rules that can be applied to the various instantiations of the stimuli, and thus reversal of targets and distractors will not necessarily lead to disruption.

In the present experiment we expand on this research by examining the performance of both older and younger adults when given CM training and multiple reversals in visual search. We used a difficult triple-conjunction search used by Ho and colleagues (2003) because it provided the flexibility of manipulating both the type and the number of features that distractors shared with a target. A difficult triple-conjunction search also involves more cognitive demand than the two-dimensional search used by Ho and Scialfa (2002), and thus the age differences that are reported from semantic category search (Fisk & Rogers, 1991; Rogers & Fisk, 1991) may materialize. We investigated two sets of predictions, the first pertaining to the role of priority learning in the development of proficient search and the second related to the priority-learning deficit hypothesis.

If priority learning is the mechanism subserving automatic search, then display size effects on RT should be eliminated

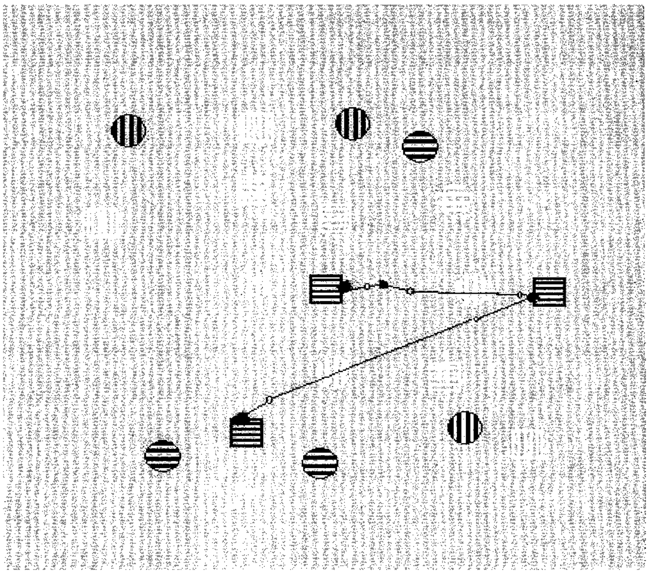

Figure 1. An example of a display used in the present experiment with eye movements superimposed.

with CM practice and reemerge whenever targets that have become automatized are no longer relevant. There should also be a gradual increase in the frequency with which observers fixate objects sharing the target's features, because priority learning is an incremental process. Finally, reversal of target features should result in disruption in the efficiency with which observers fixate target features. In contrast, rule-based learning or rapid modulation of top-down activation would allow for the absence of disruption following changes to target features and would also predict that fixations can remain efficient across changes in superficial properties of the task, as long as the higher level consistency is in place. On the basis of the priority-learning deficit hypothesis, we predicted that younger adults would show more benefit than older adults from CM training and would also be more disrupted at initial transfer. We also predicted that older adults would more frequently fixate objects that do not share target features.

## Methods

### *Participants*

Twelve older adults ($M = 64.83$ years, $SD = 5.02$ years) and 12 younger adults ($M = 23.92$ years, $SD = 3.73$ years) participated in the experiment, and each received \$95.00 (Canadian) as remuneration for the entirety of the experiment.

Self-reports of general physical and visual health were good for both groups. No one had been hospitalized in the year prior to experimentation, and no one had any serious medical condition. Older adults had on average 20/20 acuity ($M = 1.05$ arcmin, $SD = .064$ arcmin), but younger adults ($M = .78$ arcmin, $SD = .20$ arcmin) tended to have better than 20/20 vision, $t(21) = 4.50$, $p < .001$. Intraocular pressure was within normal limits for all participants. The years of education for younger adults ($M = 15.5$ years, $SD = 3.78$ years) and older adults ($M = 17.5$ years, $SD = 2.65$ years) did not significantly differ, $t(22) = 1.50$, $p = .15$.

### *Apparatus*

We presented search displays and collected data by using the Eyegaze Development System and software from LC Technologies, Inc. (Fairfax, VA; Cleveland & Cleveland, 1992). We presented displays on a 14 in. (35.5 cm) Sony Trinitron MultiScan 100 GS Monitor. We sampled eye movements at 30.3 Hz by using the pupil center–corneal reflection technique (see Young & Sheena, 1975).

We used a height-adjustable chin rest and chair to keep the observer's head in a fixed position at a constant distance of 50 cm from the monitor and at a vertical gaze angle of approximately 0° with respect to the fixation stimulus.

We measured acuity at a distance of 50 cm by using custom-made Landolt Cs with eight targets for each level of minimum angle of resolution, which varied in steps of approximately .05 log units. We provided Trial Lenses (R. H. Burton) to those participants who required visual correction.

### *Stimuli*

Shown in Figure 1, the stimuli consisted of objects defined along three dimensions: contrast polarity (black or white), shape (square or circle), and interior line orientation (horizontal or vertical). On half of the trials, the target was present, which was either a black square with vertical stripes or a white circle with horizontal stripes. Distractors were made of other combinations of color, shape, and interior orientation, such that they shared either one or two features with the target. Display size varied with equal probability among 7, 13, and 19 objects.

The sides of each square and the diameter of each circle measured 1.19° of visual angle. The vertical and horizontal stripes of each object were approximately .06° wide and were separated by spaces of the same width. Black objects were approximately 32.39 cd/m$^2$ and white objects were 46.90 cd/m$^2$. We presented all images on a gray background that had a luminance of approximately 39.17 cd/m$^2$.

We constructed a $5 \times 5$ matrix measuring approximately 25.18° in width and 18.62° in height to place objects. Within each cell, we set a restricted active area (5.2° × 3.71°), and we randomly placed each object anywhere within the active area. The minimum interelement spacing was 0.34°.

### *Procedure*

The study consisted of 17 CM training sessions (one session per day). On Days 1 through 8, participants were trained to search for a black square with vertical stripes. On Day 9, the target was switched to a white circle with horizontal stripes. Participants were trained with this new target until Day 16. On Day 17, the target was once again switched back to the original black square with vertical stripes. The distractors remained constant throughout all 17 days.

For each session, there were 6 blocks of 36 trials, for a total of 216 trials per session. Each trial began with the fixation stimulus. Participants fixated the cross and pressed a key on the keyboard when they were ready. Once a key was pressed, the fixation screen remained visible for 0, 50, 100, or 150 ms, to prevent anticipatory searching. The search screen then appeared. Participants were instructed to search for the target and to make a "present" or "absent" response by pressing corresponding keys on the keyboard; "c" was used for present, and "m" was used for absent. Feedback was provided after each response. A plus sign indicated the participants were correct, and a minus sign indicated they were incorrect. If after 5 s no response was made, a question mark appeared and the trial ended.

## Results

Approximately 10% of the trials were discarded because of the eye tracker's failure to maintain an eye position signal. Following Ho and colleagues (2003), we had errors, RT slopes, and feature selection serve as dependent measures. We defined a fixation as two or more consecutive samples within the same 11-pixel window. We based RT on trials ending in a correct response. We calculated mean RTs after we removed latencies more than $\pm 2$ *SD*s from the participant's mean for each condition. We discuss the feature selection variable in more detail in later paragraphs.

We performed mixed-model analyses of variance (ANOVAs) on each dependent measure at each of the critical sessions, namely Sessions 1, 8, 9, 16, and 17. For error and feature selection analyses, age served as a between-subjects variable, and the session, target presence, and display size served as within-subjects variables. For RT, the display size effect can be captured in the slope estimate if any systematic effect is linear in nature. An analysis of individual data indicated that, on average, the linear functions accounted for more than 95% of the display size effect. Of the 240 data points that entered into the following analyses, there were only ~8% where more than 10% of the variance in the effect was nonlinear, and these arose because the display size effect was quite small. Thus, we used slopes of display size effects as dependent measures, and, as a result, we submitted the data to an Age (2) × Target presence (2) mixed-model ANOVA. To examine disruption effects for RT, we calculated disruption scores as a percentage of change from the sessions immediately before and after reversals (Rogers & Fisk, 1991). We did not calculate disruption scores for errors because some participants made no errors, and thus disruption scores would have been incalculable. For the sake of brevity, we report only significant findings.

### *Errors*

The percentage of errors made by both younger and older adults is shown in Figures 2A and 2B, respectively, over the entirety of the experiment. Error rates were generally low, averaging between 3% and 6%. Throughout the experiment, the effects of display size and target presence were inconsistent. The only systematic finding was that younger adults made more errors than older adults, particularly after the first transfer. This concerned us, because it may reflect a speed–accuracy trade-off among participants. That is, younger adults may be sacrificing errors for speed, whereas older participants may be doing the opposite (Botwinick, 1978; Kramer, Strayer, & Buckley, 1990). This may also explain why older adult slopes are disproportionately higher for target-absent trials (Ho & Scialfa, 2002; Strayer & Kramer, 1994c).

Five younger participants were noted to have substantially more errors (6.76 %) than the other younger adults (1.98%) and the older participants (1.12%). Relative to the more accurate younger participants, these five younger participants also had significantly faster RTs as a function of display size ($p < .05$) at Sessions 1, 8, and 9. Thus, for these five individuals, accuracy

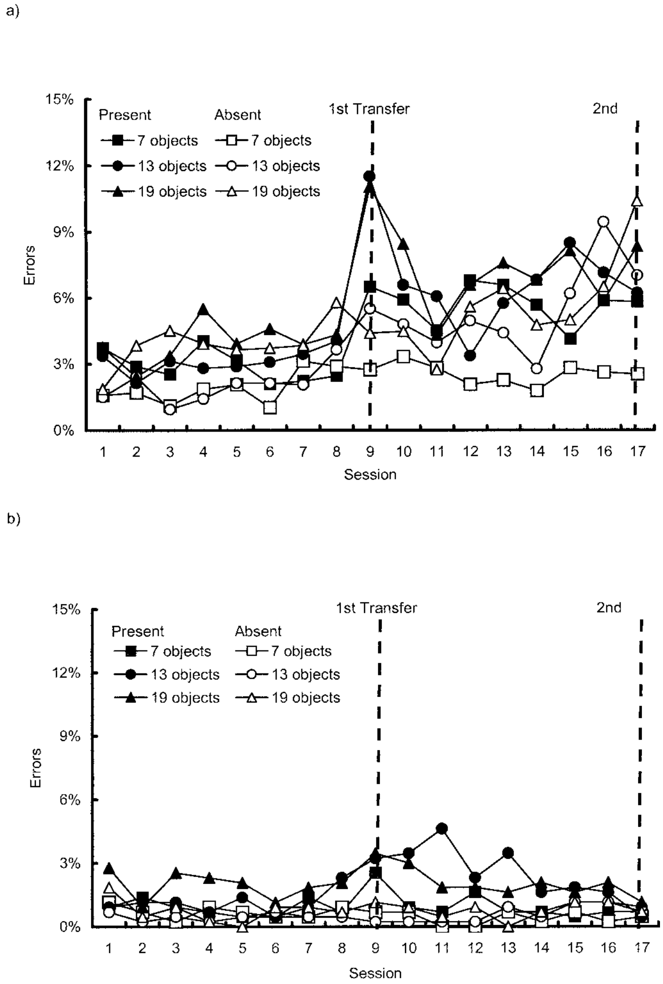


Figure 2. Average percent errors over all 17 sessions of the experiment (**A**, younger adults; **B**, older adults).

was being sacrificed for speed through the first half of the experiment.

Although this was a concern, we do not believe the RT data are problematic. First, when comparing those younger participants with high accuracy and low accuracy, we found no RT differences between Sessions 16 and 17, suggesting that even those who kept their accuracy high were able to reach asymptotic levels of performance. Second, we found no feature-selection differences between these two groups of younger participants. Thus, the best indicator of priority learning, the likelihood of fixating and attending objects sharing the target's features, is not compromised. Third, tests comparing only the younger, more accurate participants and all older participants revealed identical effects to what is reported in the following sections, which include data from all observers.

*Session 1.*—In the first session, the only significant effect was that more errors were made on target-present trials (2.4%) than on target-absent trials (1.4%), $F(1, 22) = 6.99$, $p = .015$.

*Session 8.*—After participants were trained to look for a black square with vertical stripes for eight sessions, only the main

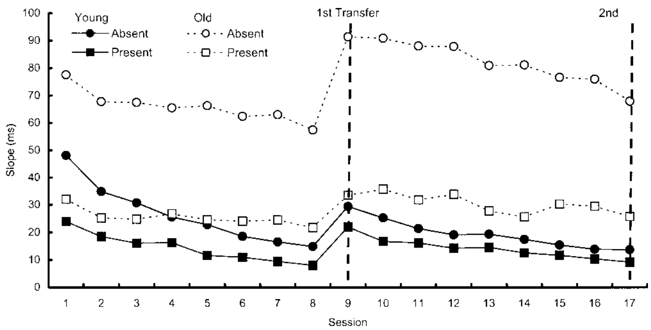


Figure 3. Average RT slope in milliseconds over all 17 sessions for both younger and older adults.

effect of age was significant, with younger adults making more errors (3.5%) than older adults (1.2%), $F(1, 22) = 5.22$, $p = .032$.

*Session 9.*—Younger adults had significantly more errors than older adults (6.4% vs 1.9%), $F(1, 22) = 11.24$, $p = .003$. Moreover, errors were greater for both of the larger display sizes (4.2% vs 2.9%), $F(2, 44) = 3.94$, $p = .05$. It also appears that introducing the new target presented the most difficulty on target-present trials relative to target-absent trials (6% vs 2.2%), $F(1, 22) = 46.87$, $p < .001$. That is, participants tended to miss a signal more often. This appeared to be particularly true for younger adults who committed more errors than older adults, whereas on target-absent trials, age differences were less pronounced, $F(1, 22) = 6.33$, $p = .02$. No other effects were significant.

*Session 16.*—After participants were trained on the white circle with horizontal stripes, age effects remained. Younger adults still made more errors than older adults (5.6% vs 1.2%), $F(1, 22) = 12.04$, $p = .002$. Display size effects were also significant, $F(2, 44) = 4.48$, $p = .026$, but unsystematic. More errors were made on Display Size 13 than the other display sizes.

*Session 17.*—After reintroducing the black square with vertical stripes as the target, we found that age differences persisted. Again, younger adults had more errors than older adults (6.1% vs .7%), $F(1, 22) = 14.27$, $p = .001$. Display size effects were also evident, $F(2, 44) = 8.77$, $p = .001$, and display size effects were greater for younger adults relative to older adults, $F(2, 44) = 6.53$, $p = .004$.

## *RT Slopes*

Figure 3 shows RT slopes for both older and younger adults as a function of target presence across all 17 sessions. Several trends are apparent. First, with practice, both older and younger participants reduced slopes. Second, only the target-present slopes for younger adults were small enough to indicate automatic performance. Older adults continued to exhibit considerable display size effects, especially on target-absent trials. Third, at the first transfer, both groups exhibited some disruption, whereas at the later transfer, disruption was minimal.

*Session 1.*—At first session of practice, slopes were greater for older adults relative to younger adults (55 vs 36 ms/item), $F(1, 22) = 11.53$, $p = .003$, and target-absent slopes were greater than target-present slopes (28 vs 62 ms/item), $F(1, 22) = 122.32$, $p < .001$. For younger adults, the average target-absent slope (48 ms/item) was twice that of the average target-present slope (24 ms/item). For older adults, the target-absent slope (78 ms/item) was greater than twice the target-present slope (32 ms/item), resulting in a significant Age $\times$ Target presence interaction, $F(1, 22) = 11.44$, $p = .003$.

*Session 8.*—After eight sessions of CM training, both age groups reduced their display size effects; however, slopes for younger adults (11 ms/item) were still significantly smaller than slopes for older adults (40 ms/item), $F(1, 22) = 57.55$, $p < .001$. Target-present slopes continued to be smaller than target-absent slopes (15 vs 37 ms/item), $F(1, 22) = 57.49$, $p < .001$, and the Age $\times$ Target presence interaction was also significant, $F(1, 22) = 26.60$, $p < .001$. On target-present trials, younger adults had slopes near zero (8 ms/item), whereas older adults continued to show a considerable display size effect (22 ms/item). On target-absent trials, display size effects were still evident for both age groups. Average slopes were 15 ms/item and 58 ms/item for younger adults and older adults, respectively.

*Session 9.*—Both age groups had difficulty with the switch to a white circle with horizontal stripes, but display size effects were greater for older adults (26 vs 64 ms/item), $F(1, 22) = 38.11$, $p < .001$. Display size effects were also larger on target-absent trials relative to target-present trials (61 vs 28 ms/item), $F(1, 22) = 65.93$, $p < .001$. For younger adults, target-present slopes (22 ms/item) were comparable with target-absent slopes (30 ms/item), but for the elderly adults, target-absent slopes (92 ms/item) were nearly three times greater than target-present slopes (34 ms/item), $F(1, 22) = 39.20$, $p < .001$.

*Session 16.*—The main effect of age (12 vs 53 ms/item) persisted after training on the new target, $F(1, 22) = 71.50$, $p < .001$, as did the main effect of target presence (20 vs 45 ms), $F(1, 22) = 41.17$, $p < .001$. For younger adults, slopes were 10 and 14 ms/item for target-present and target-absent trials, respectively, whereas older adults continued to have more difficulty with target-absent trials (76 ms/item) compared with target-present trials (30 ms/item), $F(1, 22) = 30.43$, $p < .001$.

*Session 17.*—When the target was changed back to a black square with vertical stripes, there appeared to be less disruption relative to the first transfer. Slopes for younger adults were smaller than for older adults (11 vs 47 ms/item), $F(1, 22) = 86.37$, $p < .001$, and target-present slopes were smaller than target-absent slopes (17 vs 41 ms/item), $F(1, 22) = 64.10$, $p < .001$. Again, although target-present and target-absent slopes were comparable for younger adults (9 ms/item and 14 ms/item, respectively), older adults continued to show considerable display size effects that were more pronounced for target-absent trials (68 ms/item) relative to target-present trials (14 ms/item).

## *Disruption of RT*

If the proficient search that develops with practice is the result of an involuntary process as proposed by strength theory, then changing the task so that previously ignored features are

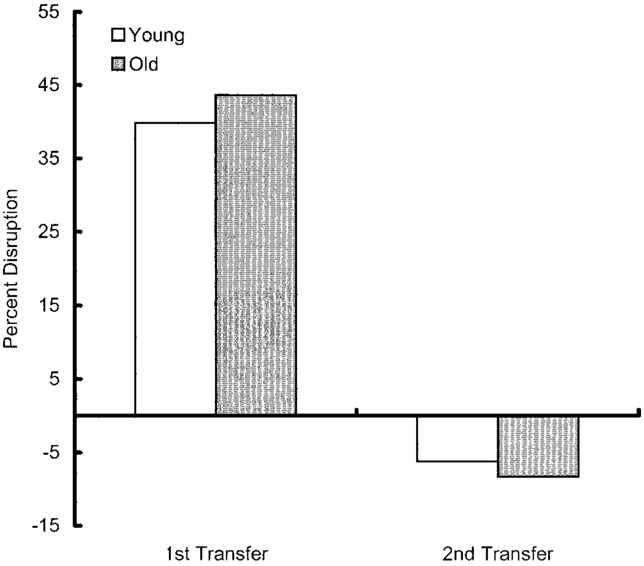


Figure 4. Disruption scores presented as a percentage for the first and second transfer periods for both younger and older adults.

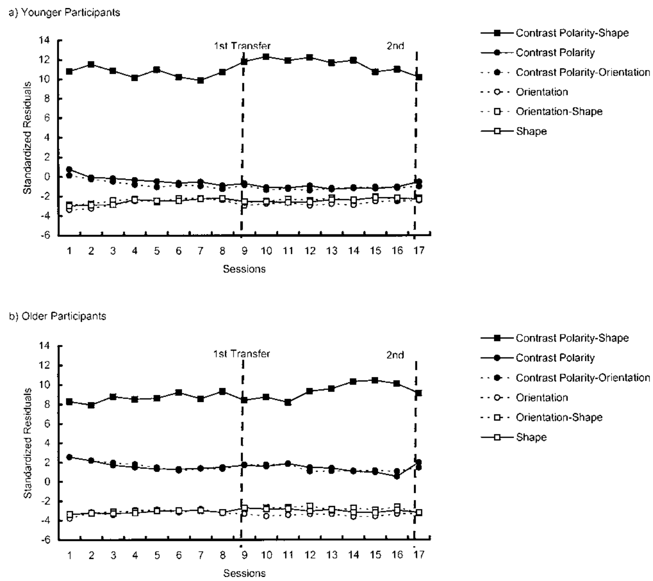


Figure 5. Average feature selection measured in standardized residuals over all 17 sessions of the experiment (**A**, younger adults; **B**, older adults).

now relevant should result in a disruption in RTs that is greater for larger displays. Thus, slopes should increase dramatically at reversal. Furthermore, if age deficits in search are the result of a priority-learning deficit, then elderly adults will show less disruption at reversal than their younger counterparts.

Figure 4 shows the disruption data for each of the transfers. Disruption greater than 35% is evident after the first transfer, but not after the second, where, in fact, positive transfer is seen. Age differences for neither the initial transfer, $t(22) = .537$, $p = .597$, nor the subsequent transfer, $t(22) = .642$, $p = .531$, were significant. Thus, despite age differences in display size effects and target-presence effects during practice, the amount of interference as a result of previous training was equivalent for both age groups.

## *Feature Selection*

If priority learning is the basis of proficient search, then one would expect that, over time, observers would differentially fixate objects that share target features; that is, they would attend efficiently to relevant features and ignore irrelevant features. Thus, if the target is a black square with vertical lines, fixations should land disproportionately on objects that have these properties. To analyze the features that participants were attending, we calculated a variable termed *feature selection* (Ho et al., 2003). Feature selection is the difference between the frequency with which an object was fixated and the expected frequency of fixating that object under the assumption of a random model. This difference is a residual, as in a chi-squared test. The sign of the residual indicates whether the object was fixated more or less frequently than would be expected under a random model. We present the data as standardized residuals to control for baseline differences in fixations across conditions. A standardized residual in excess of $|1.96|$ is considered significant. Because target-absent trials result in more frequent fixations, more reliable estimates of feature selection are derived from this condition. Thus, we chose to analyze only target-absent trials. In addition, because no display size effects were significant, the following analyses collapse across display size.

Several trends can be seen in Figure 5. First, it is clear that, from the outset of practice and continuing through the protocol, both older and younger participants preferred to look for objects that shared the target's contrast polarity and shape. This was followed by fixations made toward the objects that shared at least contrast polarity with the target. Objects that did not share contrast polarity with the target were rarely fixated. Second, no disruption can be seen at either transfer. People continued to use contrast polarity and shape to guide their search regardless of the specific target features. Last, older and younger participants appear to exhibit the same patterns in searching behavior, using contrast polarity and shape as the prominent features to attend. To examine this statistically, we submitted the data to an Age (2) × Object type (6) mixed-model ANOVA at each of the critical sessions.

*Session 1.*—The effect of object type was significant, $F(5, 105) = 298.25$, $p < .001$, because for the most part participants fixated on the black square with horizontal stripes more than the other distractor objects. The Age × Object type interaction was also significant, $F(5, 105) = 9.48$, $p < .001$. Compared with older adults, younger adults fixated more often on black squares, $t(21) = 2.79$, $p = .011$, and ignored the black circle with the vertical stripes, $t(21) = -4.48$, $p < .001$, and objects with horizontal stripes, $t(21) = -4.31$, $p < .001$.

*Session 8.*—The pattern shown in Session 1 persisted in Session 8. The effect of object type was significant, $F(5, 105) = 282.84$, $p < .001$, as was the Age × Object type interaction, $F(5, 105) = 9.81$, $p = .001$. Although both younger adults and older searched by selecting black squares, again older adults more often looked at black circles with vertical stripes, $t(21) = -5.67$, $p < .001$, and black circles with horizontal stripes,

$t(21) = -7.14$, $p < .001$. However, relative to their younger counterparts, older adults made fewer fixations on the white square with vertical stripes, $t(21) = 2.92$, $p = .008$, and the white square with horizontal stripes, $t(21) = 3.77$, $p = .001$.

*Session 9.*—After the first transfer, if participants were to show disruption in feature selection, eye movements would still be directed to black squares. This did not occur. Instead, white circles were fixated more than all other distractors, $F(5, 105) = 444.40$, $p < .001$. Fixations toward objects differed between age groups, $F(5, 105) = 21.78$, $p < .001$. Younger adults fixated white circles more than older adults, $t(21) = 4.54$, $p < .001$, and older adults were more distracted by both the white squares with the vertical orientation, $t(21) = -6.23$, $p < .001$, and white squares with horizontal orientation, $t(21) = -6.91$, $p < .001$.

*Session 16.*—After eight sessions in which a white circle with horizontal stripes was searched for, fixations remained predominantly directed toward white circles, $F(5, 105) = 369.77$, $p < .001$, and age differences as a function of object type persisted, $F(5, 105) = 6.68$, $p = .006$. Older adults directed more fixations toward both the white squares with vertical stripes, $t(21) = -5.50$, $p < .001$, and horizontal stripes, $t(21) = -4.39$, $p < .001$, but younger adults directed more eye movements toward black squares, $t(21) = 3.92$, $p = .001$.

*Session 17.*—At the final transfer, once again, neither age group showed any disruption in their feature selection. Fixations were again directed toward black squares, $F(5, 105) = 415.75$, $p < .001$. The Age $\times$ Object type interaction was also significant, $F(5, 105) = 14.52$, $p < .001$. Once again, older adults made more fixations toward both the black circle with vertical stripes, $t(21) = -5.82$, $p < .001$, and the black circle with horizontal stripes, $t(21) = -7.42$, $p < .001$. However, it was younger adults who made more fixations toward white distractors. Relative to older adults, younger adults made more fixations toward the white squares with vertical stripes, $t(21) = 3.78$, $p = .001$, white squares with horizontal stripes, $t(21) = 3.12$, $p = .005$, and the white circle, $t(21) = 3.14$, $p = .005$.

Throughout the experiment, a general pattern emerged in the feature selection data. Referring to Figure 5, three main clusters of standardized residuals were evident for both age groups. The uppermost function of standardized residuals represents objects that shared both contrast polarity and shape with the target. Clearly, these combined features were fixated more than expected by a random model, and this was true for both older and younger adults. The second cluster of standardized residuals represents those objects that shared only contrast polarity with the target and objects that shared both contrast polarity and orientation with the target. Both functions were near zero for both age groups. The third cluster of standardized residuals represents the three objects that did not share contrast polarity with the target, and, for both age groups, this cluster of standardized residuals was negative.

Although both age groups exhibited the same general pattern, relative to the young, it appeared that older adults were more distracted by objects that shared the contrast polarity but not the shape of the target. To examine this more closely, for each participant, we obtained an average standardized residual representing each of the three main clusters across the 17 sessions. We then calculated two difference variables for objects that shared contrast polarity and shape versus the other two clusters. We then submitted these difference values to separate independent-samples *t* tests comparing age groups to examine whether older adults made significantly more fixations to objects that did not share both contrast polarity and shape with the target.

The results indicated that the difference between fixations on objects sharing contrast polarity and shape versus other objects that shared only contrast polarity were greater for younger adults ($M = 12.00$, $SD = 1.85$) than they were for older adults ($M = 7.49$, $SD = 2.44$), $t(21) = 4.96$, $p < .001$. The results were not significant for objects that did not share contrast polarity with the target. That is, both younger adults ($M = 13.72$, $SD = 1.77$) and older adults ($M = 12.13$, $SD = 2.73$) were equally good at ignoring objects that did not share contrast polarity, $t(21) = 1.63$, $p = .12$.

## Discussion

There are two general sets of findings from the current experiment. The first involves the mechanisms subserving learning in CM conditions, and the second deals more specifically with aging and the development of proficient visual search. With respect to the first of these issues, the RT and error data replicate previous work examining training effects in a CM visual search (Ho & Scialfa, 2002; Ho et al., 2003; Schneider & Shiffrin, 1977). Initially, search was effortful and slow, and display size effects were large. With CM training, display size effects were considerably reduced. Disruption was evident after the initial switch of the target, but subsequent transfers produced no disruption for either age group. The feature selection data were consistent with previous triple-conjunction search studies (Ho et al., 2003; Williams & Reingold, 2001) in demonstrating that observers use multiple features to find a target (Humphrey & Kramer, 1997). Efficient feature selection was seen from the onset of the experiment and was not disrupted when the target changed.

Our results are also pertinent to the priority-learning deficit hypothesis (Fisk & Rogers, 1991; Rogers & Fisk, 1991) proposed to account for age differences in a proficient search. Relative to the young, older adults were more accurate, slower, and demonstrated larger display size effects. However, the amount of disruption did not differ across the age groups, suggesting that learning for both groups was equivalent. In addition, the feature selection data indicated that older observers were able to selectively attend to those objects that shared salient features with the target. This is consistent with prior research showing that older adults can use feature information to their advantage (Ho & Scialfa, 2002; Humphrey & Kramer, 1997). However, unlike the results of previous work in visual search, small but systematic age differences in feature selection were present. Older adults were more distracted by objects sharing the target's contrast polarity, even if they did not share shape or orientation with the target, whereas younger adults were able to ignore these objects.

### *Theoretical Issues in the Development of Proficient Search*

The lack of disruption in RT slopes at the second reversal and in feature selection at any reversal is at odds with a strength theoretic approach (Schneider & Shiffrin, 1977). Strength theory predicts that, with CM training, attention–attraction strength for the target becomes stronger; for distractors, attention–attraction strength becomes weaker. If true, each time a target is trained to asymptotic performance, a switch of the target should produce disruption. In addition, if modulation of attention–attraction strength occurs incrementally, then feature selection should require experience to become manifested. Instead, feature selection was found to be at consistently high levels from the onset of training.

What is the mechanism, then, that allows observers to search so efficiently and not be disrupted? In previous work, several options were proposed. A rule-based approach would allow observers to transfer easily from one target to another as long as there was some higher order consistency between the targets (Duncan, 1986; Kramer et al., 1990; Myers & Fisk, 1987). In this case, observers could apply the following rule: Select objects that share contrast polarity and shape with the target and then look for the orientation singleton among those objects. This rule would work regardless of whether the target was a black square or a white circle.

Another possibility is a guided search (Wolfe, 1994; Wolfe et al., 1989). In this view, search is carried out by the parallel computation of activation for each item in the display. Bottom-up activation reflects an item's perceptual ''contrast'' with other elements in the display, whereas top-down activation indexes match between an item and the target. This model of search would explain the lack of disruption by means of a quick modulation of top-down processes that allows observers to quickly adapt to a changing target. The area activation model of search (Pomplun, Reingold, Shen, & Williams, 2000) proposes a similar explanation. Fast top-down modulation of the appropriate target features allows for a quick expansion of the visual span, and thus proficient search immediately after transfer of a target. In this study, because the target identities were known, observers could capitalize on this information to modify feature activation levels.

There is a subtle but potentially important difference between rule-based learning and guided search. A guided search requires knowledge of target identity in order for feature-specific modulation of top-down activation to occur. In contrast, rule-based learning could, in theory, proceed with undiminished efficiency even if the target features were not explicitly known as long as the rule remained in effect. This sort of behavior is seen in tasks such as the Wisconsin Card Sorting Task and the Categories Task used in neuropsychological assessment. Whether it can be shown unambiguously to apply in visual search is a matter for future research.

### *Aging, Search, and Feature-Based Selection*

The data suggest that this flexibility in top-down modulation or rule-based learning is intact among older adults. Overall, older adults performed very similarly to their younger counterparts. They demonstrated no disruption at the second transfer, and their feature-based selection was very similar to that of the young. Despite these substantial similarities, there were consistent and significant age differences in feature selection. Described broadly, although the elderly adults efficiently ignored items that did not share the target's contrast polarity, they were less able than the young adults to select items that shared *both* contrast polarity and shape with the target. The mechanism(s) that account for these differences is open to debate.

One possibility is a priority-learning deficit (Fisk & Rogers, 1991), which predicts that, for older adults, the augmentation of attention–attraction strength to target features is reduced. As a result, older adults would be more distracted by nontarget objects. However, the data also suggest that the deficit was relatively minor. Recall that a standardized residual greater than +1.96 suggests that objects were fixated significantly more than would be predicted by a chance model. For the older adults in this study, the average standardized residual for objects sharing contrast polarity and shape was 9.04. Thus, older participants were still extremely good at selecting objects that shared both target features.

Age differences in feature-based selection may be influenced by the memory demands of a task. In our previous work involving only two perceptual dimensions, no age differences were found in feature selection and both age groups demonstrated equivalent disruption (Ho & Scialfa, 2002). Given more complex search requirements of the present triple-conjunction task, evidence of priority-learning deficits may have been able to surface. This could also help explain why age differences in priority learning are seen much more consistently in the memory-laden semantic category search (e.g., Fisk & Rogers, 1991; Rogers & Fisk, 1991) than in a relatively simple visual search involving a small number of perceptual dimensions such as orientation and contrast polarity. Similar arguments have been made by Strayer and Kramer (1994c).

Although the present evidence is consistent with a priority-learning deficit hypothesis, other considerations cannot be ruled out. According to the area activation model, those dimensions that are most salient and relevant, in this case contrast polarity and shape, are used to guide fixations to areas of peak activation, and, with experience with the display characteristics, the area that can be searched in parallel expands (Pomplun et al., 2000). It may be that older adults were less able to use features such as shape and orientation in peripheral vision, and thus had to make more eye movements to objects that shared contrast polarity in general (Ball, Beard, Roenker, Miller, & Griggs, 1988; Scialfa & Joffe, 1997; Scialfa & Kline, 1988; Sekuler, Bennett, & Mamelak, 2000).

Age differences may also arise from different strategies used by younger and older adults (Strayer & Kramer, 1994a, 1994b, 1994c). Older individuals may use a more conservative response criterion and thus require a stronger signal before responding. When a task is learned, a conservative response bias prevents older adults from attaining the same level of performance as younger adults. However, a conservative response bias only partially explains the age differences that we observed. It could not account for the age differences in feature selection.

In summary, this study supports the notion that a priority-learning deficit is one reason that older adults do not achieve the performance levels of younger adults. Whether sensory or memory demands underlie these deficits in priority learning still remains to be determined. Future studies examining semantic category searches may shed light on why discrepancies are seen in the literature. Because memory demands are much greater in a semantic category search than the search presented here, priority-learning deficits may be magnified. In future studies, researchers may also want to examine how rule-based learning and top-down knowledge are used in complex search tasks and how this use changes as we grow older.

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