Perceptual Processing and Search Efficiency of Young and Older Adults in a Simple-Feature Search Task: A Staircase Approach

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The reasons that visual search may sometimes be difficult, especially for older adults, remain important research issues. This study investigated (a) whether age-related differences can occur in simple-feature search, (b) if so, whether slowing adequately accounts for these differences, (c) whether other perceptual/cognitive factors are involved, and (d) the role of perceptual strategies. The authors tested 15 young adults (ages 18–30) and 15 older adults (ages 65–78). The target was a red disc presented among red diamonds in an array of 16 or 36 items. The forced-choice staircase procedure emphasized perceptual processing while deemphasizing decision-making and psychomotor processing. Although perceptual slowing may affect older adults’ search performance, the perceptual slowing model is not simple, and other perceptual/cognitive factors, such as spatial resolution and distractibility, also are implicated. Moreover, perceptual strategies involving perceptual grouping or suppression of distractors play a key role in explaining why search efficiency is actually better for the larger set size.

Older adults often report more difficulty than young adults do in searching for a target item within a cluttered visual scene (e.g., Ball, Roenker, & Bruni, 1990; Sekuler & Ball, 1986). Some researchers have suggested that these age-related differences in visual search occur when demands are placed on working memory or higher level cognitive processes (e.g., Madden, Pierce, & Allen, 1996; Plude & Doussard-Roosevelt, 1989). Others, however, have found significant age-related differences even for a simple-feature search in which only a minimal load is placed on working memory (e.g., Scialfa & Thomas, 1994). This suggests that perceptual factors may also affect age-related differences in search performance.

Not everyone agrees that simple-feature search can result in age-related differences (e.g., Plude & Doussard-Roosevelt, 1989). Questions remain about whether extraction of perceptual information hinders search performance more for older adults than for young adults (e.g., Gottlob & Madden, 1998; Salthouse & Somberg, 1982; Scialfa & Kline, 1988). If so, is a simple perceptual slowing model sufficient to explain age-related differences (e.g., Cerella, 1990; Salthouse, 1991)? Are there search-performance results that cannot be explained by perceptual slowing? Are other perceptual factors involved—for example, individual differences in spatial resolution (e.g., Owsley & Sloane, 1990; Schieber & Baldwin, 1996)? Are varying perceptual strategies involved, such as differences in perceptual grouping and suppression of irrelevant information (e.g., Duncan & Humphreys, 1989; Madden et al., 1996; Rabbitt, 1965)? These are important questions that need to be addressed using a method that emphasizes perceptual processing while deemphasizing decision-making and psychomotor components.

Conjunctive search tasks have often been used to study age-related differences in visual-search performance. Conjunctive search tasks place demands on working memory and higher level cognitive processes, and these may make search especially difficult. The target differs from some of the distractors by one feature and differs from the other distractors by a different feature. For example, the target could be a vertical red bar presented among vertical green and horizontal red bars. To distinguish a target from a distractor one must integrate information about the target features (e.g., the target is both red and vertical), thus placing attentional demands on working memory. Not surprisingly, age-related differences frequently have been reported for conjunctive searches and attributed to age-related differences in cognitive function (e.g., Madden et al., 1996; Plude & Doussard-Roosevelt, 1989; Zacks & Zacks, 1993).

Search can be relatively easy when minimal demands are placed on working memory and higher cognitive processes, as is often reported for simple-feature search. The target differs by at least one feature (e.g., shape, color, or size) from an array of homogeneous distractors. For example, the target could be a red vertical bar among red horizontal bars; to distinguish a target from the distractors one merely distinguishes which item has the critical feature.

However, there are conditions under which simple-feature search may not be so easy. For example, search can be affected by the ability to distinguish the target from the distractors (e.g., Ball et al., 1990; Davis & Peterson, 1998; Duncan & Humphreys, 1989; Palmer, 1995; Rogers & Fisk, 1991). If the target is very similar to the distractors, simple-feature search becomes more difficult (Duncan & Humphreys, 1989). For example, if the target differs from the distractors only in shape, this would result in a more difficult search than if the target differed from the distractors in shape, color, and size. It is more difficult to find a large red disc target embedded in an array of large red squares than in an array of small blue squares.

Some researchers have reported age-related differences in
search performance for simple-feature search (e.g., Scialfa & Thomas, 1994), but others have found no age-related differences (e.g., Plude & Doussard-Roosevelt, 1989). Age-related differences in simple-feature search performance perhaps are more likely to occur when the search is not easy even for young adults. Scialfa and Thomas (1994) found that feature search was more difficult when a target was similar to the distractors, differing from all distractors by only one dimension (e.g., shape) than when the target was dissimilar to the distractors, differing from all distractors by several dimensions (e.g., shape, size, and color). Age-related differences in search performance were also larger in the more difficult feature-search condition. Scialfa and his colleagues argued that age-related differences in simple-feature search performance are due to perceptual factors that include individual differences in visual acuity (Owsley & Sloane, 1990; Schieber & Baldwin, 1996) and the time required to perceptually process information (Scialfa & Kline, 1988; Gottlob & Madden, 1998; Madden & Allen, 1991).

A second condition under which simple-feature search may not be so easy is when the roles of the target and the distractor are switched, as reported for search asymmetry (Treisman & Gormican, 1988; Treisman & Souther, 1985). Detecting the absence of a critical feature is more demanding than detecting the presence of the feature in a visual search task. For example, looking for an O among Qs is more difficult than looking for a Q among Os. In the former case one looks for an O that lacks the critical line segment of a Q, but in the latter case one looks for the additional line segment that turns an O into a Q.

In our experiment the target was a red disc embedded in an array of red diamonds. Like Scialfa and Thomas’s (1994) condition in which the target was similar to the distractors, our target differed from the distractors only in one dimension: shape. Our disc target also lacked the critical “corner” features of the diamond distractors—to detect the target observers had to look for the absence of corners. Indeed, pilot studies confirmed that young adults found searching for a disc among diamonds not as easy as the reverse, searching for a diamond among discs. We chose the more difficult search task to investigate possible age-related differences in simple-feature search performance because such tasks may be more likely to reveal age-related differences.

In this study, we investigated how easy our simple-feature search was and whether the simple-feature search was more difficult for older adults than for young adults. If so, were differences in visual-search performance due to individual differences in perceptual factors, such as the time required to extract perceptual information or visual acuity, or to possible variations in perceptual strategies, such as perceptual grouping and suppression of irrelevant distractors? In investigating these issues we used a procedure that emphasized perceptual processes, deemphasized decision-making and psychomotor processes, reduced response bias, and eliminated many speed–accuracy tradeoff problems (e.g., Bergen & Julesz, 1983; Kliegl, Mayr, & Krampe, 1994; Zacks & Zacks, 1993). In analyzing our results we used four different methods to provide a more comprehensive interpretation of the data. Because our theoretical predictions are so closely linked to the specific method and data analyses used in this study, we describe our theoretical predictions immediately before presenting the results.

**METHODS**

**Participants**

Fifteen young adults whose ages ranged from 18 to 30 years ($M = 22.6, SD = 4.1$) and 15 older adults whose ages ranged from 65 to 78 years ($M = 69.3, SD = 3.5$) participated in this study. Within each age group there were 7 women and 8 men. The young adults were undergraduate or graduate students at the Georgia Institute of Technology who received a combination of extra course credit and payment for their participation. The older adults were volunteers recruited from the community who received payment of $10 per hour. The participation of all persons was voluntary and in accord with American Psychological Association guidelines for the use of human participants.

The young adults had an average of 16.1 years of formal education ($SD = 2.5$) and the older adults had an average of 16.4 years ($SD = 1.1$). Most reported average to excellent health at the time of testing, none reported poor health, and none was taking two or more medications that would adversely affect perceptual or cognitive aspects of attention (based on Giambra & Quilter, 1988).

Participants underwent a preliminary battery of perceptual and cognitive tests to assess individual differences in sensory function, perceptual speed, spatial ability, distractibility (failure to ignore irrelevant information), working memory, and crystallized intelligence. These test measures were collected for two purposes. First, we compared older and young adults to determine age-related differences in these factors. Second, factors that show significant age-related differences in performance may also be related to differences in visual-search performance, as described in the Results and Discussion. Near and far visual acuities were assessed with the Tumbling E and Bailey-Lovie eye charts (Ferris, Kassoff, Bresnick, & Bailey, 1982), respectively. Color vision was tested with Ishihara color plates (Ishihara, 1987) using a standard C illuminant. Perceptual speed was measured using a computerized digit–symbol test that was a modification of the Wechsler Digit Symbol Substitution Test (Salthouse, 1992). Both the Cube Comparison Test and the Surface Development Test (Ekstrom, French, Harman, & Dermen, 1976) were used to evaluate spatial ability. Participants were also tested with the color Stroop test (Stroop, 1935) as a measure of distractibility, the Reverse Digit Span Test (Wechsler, 1981) as a measure of working memory, and the Advanced Vocabulary Test (Ekstrom et al., 1976) as a measure of crystallized intelligence. Table 1 shows the scores for both young and older adults.

**Stimuli**

Figure 1 shows a schematic of the visual stimulus and mask displays for set size 16. In all visual displays the target was a red disc presented among red diamond distractors. (A pilot study showed that this combination of target and distractor shapes was more similar than many other combinations of geometric forms.) The target and distractors were displayed in either a $4 \times 4$ matrix array (for a set size of 16)
or a $6 \times 6$ matrix array (for a set size of 36). In each stimulus display, either one target was randomly positioned among the distractors or only distractors were presented. The visual-mask pattern had the same number of elements as the stimulus display and consisted of either a $4 \times 4$ or a $6 \times 6$ matrix array of white flower patterns. (A previous pilot study had shown this mask stimulus to very effectively mask the visual patterns used in our study.) Each target, distractor, or mask symbol subtended 30 minutes of visual angle when viewed from a distance of 28.5 in. The position of each item in the display was randomly jittered in both the horizontal and vertical direction by plus or minus 0.5° to reduce alignment of the stimuli. The entire $4 \times 4$ matrix was presented within a square area of $13^\circ \times 13^\circ$ of visual angle. That is, each item in the display was separated from neighboring items by approximately $2^\circ$ of visual angle, so that the density of items within the display was the same for both set sizes 16 and 36. The mean luminance of each symbol was 15.5 ft-L presented against a dark background with a luminance of approximately zero ft-L, as measured with a Pritchard 1980A photometer (Photo Research, Chatsworth, CA).

**Apparatus**

The visual displays were presented on the screen of a Sony Trinitron Multiscan 20SE color monitor. The monitor’s frame duration was 18 ms as calibrated with photodiode and oscilloscope measurements. Stimulus presentations and recording of participants’ responses were under the control of a Dell Pentium XPS-166 computer using software written in Turbo Pascal. The display was viewed from a distance of 28.5 inches so that the entire cathode ray tube screen subtended $30^\circ$ of visual angle in the horizontal direction and $22^\circ$ in the vertical direction.

**Procedures**

Two-interval forced-choice trials (2IFC).—All procedures described below used 2IFC trials to reduce response biases (e.g., Macmillan & Creelman, 1991). The participant initiated a trial by pressing 0 on the numeric keypad. Within each trial the first stimulus display was presented, immediately followed by a 500-ms mask, then the second stimulus display was presented, again immediately followed by a 500-ms mask. Masks were used to remove any afterimages of the stimulus display. A target was presented in only one of the two stimulus displays, and, on each trial, the participant had to determine whether the target had been presented in the first or second stimulus display by pressing 1 or 2, respectively. Auditory feedback was provided after each trial. The duration of the stimulus display was systematically varied throughout a block of trials by an adaptive staircase procedure, and target-detection accuracy and stimulus duration were recorded for each trial. Because the onset of the

![Stimulus Display 1](variable duration) ![Masker](500 ms) ![Stimulus Display 2](variable duration) ![Masker](500 ms)

Figure 1. Schematics of the stimulus and mask displays are shown for set size 16. A trial consists of two stimulus intervals, each followed by a mask display of 500 ms duration. The target appears in only one stimulus interval.
Adaptive staircase procedure.—An adaptive staircase procedure (e.g., Davis, 1981; Macmillan & Creelman, 1991; Penner, 1978; Rendelemen, Rose, & Teller, 1970) was used to systematically vary the SOA duration and to converge on a response-accuracy criterion of .65, .78, or .84 for 2IFC trials. These three response-accuracy criteria bracket a range of performance that is above chance but less than perfect performance so that we could estimate slopes of time–accuracy functions. We refer to these three response-accuracy criteria as low-, mid-, and high-accuracy criteria, respectively.

Each participant was tested in five blocks of staircases for each set size (16 and 36) for a total of 10 blocks of trials. For each participant, we randomized the order in which these 10 blocks were tested. Within each block, there were three interleaved staircases, one for each response-accuracy criterion (low, middle, and high accuracy). That is, within each staircase the SOA duration was systematically varied according to a set of rules designed to converge on the appropriate accuracy level, as described below.

Each staircase began with a long SOA duration of 594 ms and a maximum step size of 576 ms. Target-detection performance within each staircase was analyzed in subsets of trials to determine whether the SOA duration should be increased or decreased for the next subset of trials in that staircase. For the low-accuracy criterion of .65 correct responses, the subset consisted of three consecutive trials at a fixed SOA duration; for the middle-accuracy response criterion of .78, it consisted of five consecutive trials; and for the high-accuracy response criterion of .84, it consisted of seven consecutive trials. If two or more incorrect responses occurred within the subset of trials, the SOA duration was increased, and if all the responses were correct it was decreased.

There were 12 reversals within each staircase, such as changing from increasing the SOA duration to decreasing the SOA duration. Only the durations of the last 10 reversals were averaged together to calculate the SOA threshold duration. For each of two set sizes (16 and 36) and three response-accuracy criteria (low, mid, and high), the SOA threshold duration was based on the means from five blocks of trials for each participant (viz., 50 reversal points).

Pilot study.—Prior to conducting our visual search experiment, we ran four adults in a pilot study designed to compare search performance obtained with our adaptive staircase procedure to that obtained with the method of constant stimuli (MCS) procedure (Gescheider, 1985). Results obtained with both methods were similar—there were no systematic deviations or significant differences between the results obtained with either method for any participant. However, the MCS procedure lacks many of the beneficial features of the adaptive staircase procedure. Unlike the adaptive staircase procedure, the MCS procedure requires a priori knowledge of the appropriate range of SOA durations to test—otherwise the resulting ranges of response accuracies may all lie below the required response-accuracy criterion or else all lie above it.

Predictions We assessed ease of search in terms of a continuum from extremely easy to extremely difficult search. To determine how easy search was and whether search was more difficult for older adults than for young adults, we generated several different predictions, each corresponding to a different method of data analysis (see Table 2). Ease of search was indexed by processing time, such that more difficult search required more time to process and extract the necessary visual information, whereas easier search required less time. We evaluated processing time in two ways, by the length of time needed to search the stimulus array (SOA threshold duration measured in milliseconds) and by the average search time.

Table 2. Predictions for Simple Feature Search

<table>
<thead>
<tr>
<th>Prediction About</th>
<th>Effortless Search</th>
<th>More Effortful Search</th>
<th>Age-Related Differences^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOA Threshold Durationb</td>
<td>Equal for both set sizes SOA(SS36) = SOA(SS16)</td>
<td>Longer for set size 36 than for set size 16 SOA(SS36) &gt; SOA(SS16)</td>
<td>Longer for older adults</td>
</tr>
<tr>
<td>Set-Size Effectsc</td>
<td>No</td>
<td>Yes</td>
<td>Largest for high-accuracy responses</td>
</tr>
<tr>
<td>Time–Accuracy Functions</td>
<td>Steep TAFs</td>
<td>TAFs shallower for set size 36 Slope TAF(SS16) &gt; Slope TAF(SS36)</td>
<td>Shallower for older adults, especially for larger set size</td>
</tr>
<tr>
<td>Search Efficiency or Item Search Time^d</td>
<td>Better for larger set size [IST(SS36)/IST(SS16)] = .444</td>
<td>Equal for both set sizes or worse for larger set size [IST(SS36)/IST(SS16)] ≥ 1</td>
<td>Less efficient for older adults, especially for larger set size</td>
</tr>
</tbody>
</table>

Note: SOA = stimulus onset asynchrony; TAF = time–accuracy function; IST = item search time; SS = set size.

^a In general, simple feature search is predicted to be more effortful for older adults than for young adults.

^b Stimulus threshold duration in milliseconds.

^c Set size 16 versus set size 36.

^d In milliseconds per item.
for each item within the array (item search time [IST], or search efficiency, measured in milliseconds/item). The predictions for both set size and time–accuracy functions use the SOA threshold duration as the dependent variable, whereas those for search efficiency use the item search time as the dependent variable.

Set-Size Effects

To evaluate SOA threshold duration, we used the length of time needed to search the visual display. Set-size effects occur when more time is needed to search the visual display that contains more items. Thus, the SOA threshold duration is longer for set size 36 than for set size 16.

Extremely easy search occurs when all items in the display are simultaneously processed in parallel. If so, the SOA threshold should be equal for both set sizes and no significant set-size effects should occur.

Search may be more difficult when there are more items in the display than the observer can process simultaneously. If so, the SOA threshold duration should be longer for the larger set size, and significant set-size effects should occur, because more time is needed to search through the more numerous items of the larger set size. Moreover, set-size effects should be larger for high-accuracy performance than for low-accuracy performance. To achieve high-accuracy performance the observer must process a larger proportion of the visual array than for low-accuracy performance. For example, to process 80% of the items in each visual display, approximately 29 items are processed for the large set size, whereas only 13 items are processed for the small set size, a difference of 16 items. However, to process 60% of the items in each display, approximately 22 items are processed for the large set size, whereas approximately 10 items are processed for the small set size, a difference of 12 items. Because more time is required to process 16 additional items than to process 12 additional items, the set-size effects should be larger for the higher accuracy performance than for lower accuracy performance.

If search is more difficult for older adults, the SOA threshold durations may be longer and the set-size effects larger for older than for young adults. However, age-related proportional slowing predicts that the relative set-size effects should be equal for both young and older adults. That is, the ratio of SOA threshold durations for set size 16 versus 36 should be the same value for both young and older adults (e.g., Cerella, 1985, 1990). If the ratio is significantly smaller for older adults, this indicates that proportional slowing cannot account for age-related differences in search performance, although it does not rule out more sophisticated models of age-related slowing (e.g., Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990).

Time–Accuracy Functions (TAFs)

A TAF shows the response accuracy or sensitivity as a function of the time used to search a visual array. The slope of the TAF is a measure of the ease or difficulty of the search, where the slope is the change in accuracy versus the change in SOA threshold duration. A steep function indicates an easier search, so that a small increase in SOA duration causes a big improvement in response accuracy. Conversely, a shallow function indicates a more difficult search, so that a large increase in SOA duration results in only a modest improvement in accuracy.

If search is extremely easy, the TAF slopes for large and small set sizes should be very steep and the two functions should overlap. This suggests that all of the displayed items are processed in parallel.

If search is more difficult, however, the TAF slope will be shallower for the large set size than for the small set size. The reasons are similar to those used to explain set-size effects. First, more time is needed to search through the display with more numerous items (viz., larger set size). Second, to achieve high-accuracy performance, the observer must process a larger proportion of the visual array than for low-accuracy performance. Let us use our previous example for set-size effects. For the large set size approximately 29 items are processed to achieve higher accuracy performance whereas only 22 items are processed to achieve lower accuracy performance, a difference of 7 items. For the small set size approximately 13 items are processed to achieve higher accuracy performance whereas 10 items are processed to achieve lower accuracy performance, a difference of 3 items. Because more time is needed to process the additional 7 items than to process the additional 3 items, the TAF slope is shallower for the larger set size.

If search is more difficult for older adults, they should have shallower TAF slopes than young adults. That is, older adults may need more time to extract perceptual information from the visual display. Tasks that require searching through more items of a display make age-related differences in perceptual slowing more apparent, such as search conditions that require better performance accuracy or ones with a larger set size.

Search Efficiency

The other measure of processing time is search efficiency, the average search time for each item in the visual display, measured in milliseconds per item. Zacks and Zacks (1993) provided a novel approach in which search efficiency can be calculated for a single data point. Their method let us calculate search efficiency for each individual set size and response-accuracy criterion, unlike more conventional estimates of search efficiency.

Extremely easy search arises when parallel, unlimited capacity processing occurs, so that the total search time is the same regardless of the number of items in the display. The average IST is proportional to the total search time divided by the set size. Thus, extremely easy search predicts search efficiency should be better for the larger set size. In comparing set sizes 16 and 36, extremely easy search predicts that the ratio of search efficiencies should be approximately .444 (viz., IST(set size 36)/IST(set size 16) = 16/36 = .444).

Search may be more difficult because only one item can be processed within a glimpse (serial processing) or because only a small, fixed number of items can be processed within a glimpse (fixed limited capacity). A visual display with more items (larger set size) will require more glimpses and, thus, more time to search the array than would a display with fewer items. These serial processing and fixed capacity

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versions of more difficult searches predict that search efficiency is approximately the same for both set sizes, if no information is lost across glimpses. That is, the average IST is a constant value for both set sizes.

Search may be less efficient for older adults than for young adults, especially for the larger set size. If so, this may occur because older adults have a more restricted capacity limitation. Other reasons are also possible for this age-related difference in performance, as explained in the Discussion.

RESULTS

Overview

Below we evaluate the effects of age group (young vs. older), set size (16 vs. 36), and response-accuracy criterion (low, mid, and high) on search performance. Three of the analytic methods were within-context analyses that evaluated the data within the context of the search task and let us test the predictions shown in Table 2. The fourth method was an out-of-context analysis that evaluated search data using test measures obtained from a completely different set of tasks (e.g., Madden, Pierce, & Allen, 1996; Salihouse, 1996). This out-of-context analysis was an exploratory hierarchical multiple regression analysis (hMRA) that suggested perceptual and cognitive factors that may be related to individual differences in search performance.

Overall, SOA threshold durations were longer for set size 36 than for set size 16, so significant set-size effects occurred, with the largest set-size effects found for the high-accuracy responses. Older adults had longer SOA threshold durations and larger set-size effects than young adults did. These age-related differences were especially salient for the high-accuracy responses and were obtained even for relative set-size effects. Time–accuracy functions were shallower for the larger set size and for older adults. Search efficiency was better for the larger set size, as determined using Zacks and Zacks’s (1993) method. Moreover, older adults had worse search efficiency and showed relatively less improvement in search efficiency for the larger set size than did young adults. Finally, the hMRA showed that individual differences in spatial resolution, perceptual speed, and distractibility may have affected search performance.

Set-Size Effects

We analyzed the SOA threshold durations using a repeated-measures analysis of variance (ANOVA), for which both set size and response accuracy were within-subject factors and age group was a between-subjects factor. We first analyzed the entire set of data from all 30 participants. We then excluded data from any participant whose scores deviated by more than 3 standard deviations from the mean of the appropriate age group and reanalyzed the data. Only one older participant’s data were excluded in the second analysis; this individual (S309) had much longer SOA threshold durations and much larger set-size effects than any other participant. However, we obtained the same pattern of results whether the outlier data were included or excluded from the analysis. The results reported below exclude the outlier data.

In general, participants had much longer SOA threshold durations when searching for a target among 36 items (M = 179.3, SEM = 12.67) than for a target among 16 items (M = 122.56, SEM = 8.00), so significant set-size effects occurred, F(1,27) = 73.2, p < .001 (see Figure 2). The SOA threshold durations were longer for the high-accuracy responses than for lower-accuracy responses, F(1,27) = 120.23, p < .001, and longer for mid-accuracy responses than for low-accuracy responses, F(1,27) = 118.31, p < .001, as determined by difference contrasts of the repeated-measures ANOVA. Moreover, the set-size effects also were largest for the high-accuracy responses, F(1,27) = 30.03, p < .001, and larger for the mid-accuracy responses than for the low-accuracy responses, F(1,27) = 38.97, p < .001.

Older adults had significantly longer SOA threshold durations (M = 214.4 ms, SEM = 29.4) than did young adults (M = 91.62 ms, SEM = 11.01), F(1,27) = 49.33, p < .001. Older adults also had larger set-size effects, as shown by a significant Age Group × Set Size interaction, F(1,27) = 25.87, p < .001. The age-related changes in set-size effects were largest for high-accuracy responses, F(1,27) = 7.18, p = .012, and larger for mid-accuracy responses than for low-accuracy responses, F(1,27) = 8.89, p = .006, as determined by difference contrasts of the repeated-measures ANOVA.

Because a proportional slowing model can predict the obtained age-related interactions (e.g., Cerella, 1985, 1990; Salihouse, 1991), we also evaluated the relative effect of set size on performance for young and older adults. In a separate ANOVA, we used the log-transformed values of SOA thresholds and found both significant age-related differences, F(1,27) = 54.55, p < .001, and significant Age Group × Set Size interactions, F(1,27) = 9.21, p = .005, contrary to the predictions of a proportional slowing model.
TAFs
To evaluate search performance in terms of SOA threshold duration we also used TAFs, for which a shallower function indicates more difficult processing (e.g., Bergen & Julesz, 1983; Kliegl et al., 1994; Wolfe, 1999). We used a repeated-measures ANOVA of the individual slope parameters to evaluate TAFs, with set size as a within-subjects factor and age group as a between-subjects factor. In performing this analysis, we followed Kliegl and colleagues’ (1994) suggestion and used the reciprocal of the slope, which is the time required to improve sensitivity by a constant amount (\(\Delta m/s/\Delta d'\)). This parameter is scaled in units of time, is the same metric as response-latency tasks typically used in visual-search experiments, and makes interpretation of the data more intuitive. We refer to the reciprocal of the slope as the unit processing time.

The TAF slopes were shallower for set size 36 (\(M = .001, SEM = .002\)) than for set size 16 (\(M = .020, SEM = .005\); see Figure 3). That is, the unit processing time was significantly greater for the larger set size (\(M = 188.2\) ms, \(SEM = 33.22\)) than for smaller set size (\(M = 106.2\) ms, \(SEM = 18.38\)), \(F(1,28) = 21.55, p < .001\). Extremely easy processing predicts that the TAFs for set sizes 16 and 36 should be steep and overlapping so that the TAF slopes for the two set sizes are the same. Thus, the TAF results also indicated that the search was not extremely easy.

Older adults had shallower TAF slopes than did young adults, especially for the larger set size. That is, the unit processing time was longer for older adults (\(M = 228.75\) ms, \(SEM = 31.9\)) than for young adults (\(M = 65.64\) ms, \(SEM = 8.82\)), \(F(1,28) = 16.44, p < .001\), and there was a significant Age Group \(\times\) Set Size interaction, \(F(1,28) = 9.48, p = .005\). A separate repeated-measures ANOVA used the log-transformed values of the slope parameters and showed a significant age-related difference in slope, \(F(1,27) = 29.39, p < .001\), but no significant Age Group \(\times\) Set Size interaction, \(F(1,27) = .732, p > .10\). Our TAF results suggested visual search was somewhat difficult, perhaps especially for older adults.

Equal-Accuracy State–Trace Functions
Kliegl and colleagues (1994) used equal-accuracy state–trace functions to compare the time-demand characteristics for two different tasks. We also used this method to compare the time demand to search for a target embedded in either 16 or 36 items (see Figure 4). A state–trace graph displays the covariation of two variables. In our search experiment these two variables corresponded to the processing time to detect a target for set size 16 or 36. These were equal-accuracy state–trace functions because the processing time to achieve a specified level of accuracy for one set size was plotted as a function of the processing time to achieve the same level of accuracy for the other set size. Functions with a slope steeper than 1 indicated that more time was needed to detect a target within the larger set size. The equal-accuracy state–trace functions had steeper slopes for older adults (\(M = 1.924, SEM = .199\)) than for young adults (\(M = 1.543, SEM = .186\)), but this difference was only marginally significant, one-tailed \(t(28) = -1.4, p = .087\). Of the 15 steepest slopes, 10 represent the data of older adults. These results suggest that older adults may find search relatively more difficult for the larger set size than do young adults.

Zacks and Zacks’s (1993) Method of Evaluating Search Efficiency
Zacks and Zacks’s (1993) method let us estimate search efficiency for each set size. Using this method we assessed how search efficiency may change as a function of set size as well as of age group or response-accuracy criterion.

To use Zacks and Zacks’s (1993) method of calculating IST, we first calculated the actual proportion of the visual array that was searched for low-, mid-, or high-accuracy criteria, as described by Zacks and Zacks (p. 804). That is, we estimated a correction factor \(C_{\text{det}}\) from the observed proportion correct on 2IFC trials \(C_{\text{obs}}\) using the following equation:

\[C_{\text{det}} = (2C_{\text{obs}} - 1).\]

The values for \(C_{\text{det}}\) are shown in Table 3. We then calculated the IST for each set size and each response-accuracy criterion using the following equation:
IST = (SOA threshold duration)/(C_{det} \times \text{set size}),

where the set size was either 16 or 36.

A repeated-measures ANOVA was performed on search efficiency measures, with set size and response-accuracy criterion as within-subject factors and age group as a between-subjects factor. One older participant’s data (S309) were excluded from the data analysis reported below because that individual’s search efficiency values were outliers for the older age group.

One important result is that search efficiency was better for set size 36 than for set size 16, both for young and older adults and for all response-accuracy criteria (see Figure 5). That is, IST was significantly shorter for set size 36 ($M = 9.63 \text{ ms/item, SEM = .54}$) than for set size 16 ($M = 15.09 \text{ ms/item, SEM = .80}$), $F(1,27) = 79.97, p < .001$. Overall, there was no linear change in search efficiency as a function of response accuracy, $F(1,27) = 2.59, p > .10$, although search efficiency was best for the mid-accuracy responses, $F(1,27) = 27.81, p < .001$.

Age-related differences.—Search efficiency was worse for older adults ($M = 17.17 \text{ ms/item, SEM = .69}$) than for young adults ($M = 7.87 \text{ ms/item, SEM = .39}$), $F(1,27) = 43.43, p < .001$. There was also a significant Age Group $\times$ Set Size interaction, $F(1,27) = 3.47$, or, equivalently, a one-tailed $t$ test of $t(28) = 1.86, p = .0365$. In a separate analysis we used log-transformed values of search efficiency to evaluate the relative improvement in search efficiency. As predicted, the relative improvement in search efficiency was less for older adults than for young adults, as revealed by a significant Age Group $\times$ Set Size interaction, $F(1,27) = 10.88, p = .003$.

There was also an Age Group $\times$ Response Accuracy interaction—a polynomial contrast showed a significant linear trend, $F(1,27) = 5.04, p = .033$, but no quadratic trend, $F(1,27) = .004, p = .912$. For young adults, search efficiency was better for high-accuracy responses than for low-accuracy responses, but this was not true for older adults. There was no significant three-way interaction for Age Group $\times$ Set Size $\times$ Response Accuracy, $F(2,27) = .12, p = .88$.

### Table 3. Three Representations of Response-Accuracy Criterion for Two-Interval Forced-Choice (2IFC) Trials

<table>
<thead>
<tr>
<th>Criterion</th>
<th>$C_{\text{obs}}$</th>
<th>$C_{\text{det}}$</th>
<th>Sensitivity ($d'\text{a}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>.653</td>
<td>.306</td>
<td>.558</td>
</tr>
<tr>
<td>Mid</td>
<td>.784</td>
<td>.568</td>
<td>1.110</td>
</tr>
<tr>
<td>High</td>
<td>.843</td>
<td>.686</td>
<td>1.429</td>
</tr>
</tbody>
</table>

*Notes: $C_{\text{obs}}$ = proportion correct observed; $C_{\text{det}}$ = proportion correct detected.  

$aC_{\text{det}} = (2 \times C_{\text{obs}}) - 1$ as described in the text and Zacks and Zacks (1993, p. 804).  

*b These $d'$ values for 2IFC data are given in Table A5.2 of Macmillan and Creelman (1991).
response-accuracy criteria. Because there were some small changes in search efficiency as a function of response accuracy, we performed statistical tests for each response-accuracy criterion to see if the same pattern of results was obtained throughout. As predicted in Table 2, young adults showed relatively more improvement in search efficiency for the larger set size than did older adults. That is, younger adults had significantly smaller ratio values than did older adults.

Our results were not consistent with the strict predictions of extremely easy search because the ratio of IST(set size 36)/IST(set size 16) was significantly greater than .444, as shown in Table 4. Our results also were not consistent with the strict predictions of extremely difficult search because the ratio also was significantly less than 1. However, all of these results were consistent with the concept of a continuum of ease in performing the search task, from extremely easy to extremely difficult search; the implications are considered in the Discussion.

For each of the above analyses both the group means and the pattern of results for each age group were very representative of the individuals within that group. These analyses were all within-context analyses directed toward evaluating how easy our simple-feature search was and whether search was more difficult for older adults than for young adults. Although perceptual slowing may account for some age-related differences in the results, other factors may contribute to both age-related and age-independent individual differences in search performance.

Regression Analysis of Aging, Perceptual/Cognitive Measures, and Search

We used an exploratory hMRA to identify potential perceptual and cognitive factors associated with individual differences in search performance. This out-of-context analysis is similar to that used by Salthouse (1996) and by Madden and colleagues (1996). In our analysis, however, we considered several additional perceptual and cognitive factors that those researchers had not considered.

An initial regression analysis revealed significant age-related differences in simple-feature search performance, as did the previous analyses. The participants’ chronological age was positively correlated with both SOA threshold duration and set-size effects for high-accuracy responses. For a visual display of 16 items, age was associated with approximately 36% of the variance in SOA threshold duration (R^2 = .357, R = .615), F(1,28) = 17.1, p < .001, whereas for a display of 36 items age was associated with approximately 40% of the variance (R^2 = .402, R = .650), F(1,28) = 20.49, p < .001 (Cohen & Cohen, 1983). Chronological age was associated with approximately 29% of the variance in set-size effects (R^2 = .291, R = .562), F(1,28) = 12.90, p = .001.

We used an exploratory hMRA to determine what perceptual and cognitive factors were associated with individual differences in simple-feature search performance. As measures of these factors, we used the results from our preliminary battery of perceptual and cognitive tests (see Table 1). Age-related differences in these factors have been previously reported (e.g., Salthouse & Sonberg, 1982; Schieber & Baldwin, 1996), and at least some of these factors may be associated with age-related as well as age-independent individual differences in simple-feature search. Factors that affect information processing at earlier stages were considered before those that affect information processing at later stages. That is, we used a stepwise regression to consider the perceptual and cognitive measures in the following order: (a) sensory functions, (b) perceptual speed, (c) spatial ability, (d) distractibility, (e) working memory, and (f) crystallized intelligence. After each set of factors we determined whether age was associated with any unexplained variability in search performance.

Our exploratory regression analysis suggested that sensory factors, perceptual speed, and distractibility might affect visual-search performance. We found that near visual acuity, digit–symbol substitution, and Stroop interference (as measured by differences in reaction time) were significantly correlated with SOA threshold duration. For set size
these three measures were associated with almost 60% of the variance in SOA threshold duration ($R^2 = .591$, $R = .796$), $F(3,26) = 14.95$, $p < .001$. For set size 36 the three measures were associated with approximately 80% of the variance ($R^2 = .802$, $R = .907$), $F(3,26) = 40.07$, $p < .001$. Figure 6 shows the predicted versus obtained SOA threshold duration for both set sizes.

For set-size effects, however, only sensory function and distractibility were significantly related to search performance. In this case, near visual acuity and Stroop interference were associated with almost 60% of the variance in the set-size effects ($R^2 = .606$, $R = .796$), $F(2,27) = 23.3$, $p < .001$ (see Figure 6). Perceptual speed, as indexed by digit-symbol substitution measures, was not significantly correlated with the set-size effects.

Neither chronological age nor age group was significantly associated with search performance once the perceptual and cognitive factors of visual acuity, perceptual speed, and distractibility had been considered. This implies that 100% of the age-related variance in both SOA threshold duration and set-size effects was predicted by individual differences in these three factors. These three perceptual and cognitive factors mediated both age-related and age-independent individual differences in search performance.

As Lindenberger and Pötter (1998) have shown, if the partial correlation between a mediator variable and the dependent variable is not equal to zero when age is controlled, the interpretation of linear regression data is complicated. In this case, one cannot clearly separate age-related differences from age-independent individual differences in the mediator variable. That is, although there were significant age-related differences for each of the three perceptual and cognitive factors, as shown in Table 1, we could not obtain pure estimates of age-related differences in search performance mediated by these perceptual and cognitive factors.

DISCUSSION

Most of our results suggest that the simple-feature search is not extremely easy for the stimulus set that we used. The SOA threshold durations are longer for the larger set size. Significant set-size effects occurred, and these are largest for high-accuracy responses, as predicted for more difficult search. The time–accuracy functions are shallower for the larger set size, as predicted for more difficult search. One wrinkle in this interpretation is that search efficiency actually is better for the larger set size, as predicted for extremely easy search, although the improvement in search efficiency is less than predicted.

Our results also suggest that older adults may find the simple-feature search more difficult than do young adults when the target is a disc embedded among diamonds. Older adults require more time than young adults to extract visual information from the display, as manifested by the older adults’ longer SOA threshold durations, larger set-size effects (especially for high-accuracy responses), and shallower time–accuracy functions. Although perceptual slowing could explain many of these age-related differences in search performance, proportional generalized slowing could not account for the age-related differences in either the relative set-size effects or the slopes of the equal-accuracy state–

![Figure 6](https://example.com/figure6.png)

Figure 6. An exploratory, hierarchical multiple regression analysis was used to predict stimulus onset asynchrony (SOA) threshold durations and set-size effects for high-accuracy responses, as described in the text. The diagonal line represents a perfect correspondence between predicted and obtained SOA threshold durations. Each data point represents the result for an individual participant.
trace functions. Nor could slowing explain why search efficiency is better for the larger display set size of 36 items, even for the older adults. These raise additional issues in interpreting age-related differences in search performance.

Although the above analyses are silent about other perceptual or cognitive factors that may affect search performance, an exploratory hMRA reveals that in addition to perceptual slowing, both spatial resolution and distractibility are associated with individual differences in visual-search performance. As Lindenberger and Pötte (1998) have shown, however, we cannot clearly separate age-related differences from age-independent individual differences in these variables.

Our diverse methods of data analysis provide more in-depth understanding of the underlying information processing than would any single method. In the future we would like to apply these diverse analyses to different shape combinations and stimulus dimensions (e.g., size and color) to see how the findings reported here generalize to other simple-feature search conditions. Although these methods can provide converging and complementary evidence, we must smooth out some wrinkles to provide a coherent explanation of the data from our current experiment. Integrating information across the diverse data analyses will help us to do so.

**Why Is Simple-Feature Search Not Extremely Easy?**

We had expected our simple-feature search might not be extremely easy for reasons suggested previously. First, the target is very similar to the distractors because the two differ only in shape, not in several different dimensions such as shape, color, and size (e.g., Duncan & Humphreys, 1989; Scialfa & Thomas, 1994). Second, because the red disc target lacks a critical feature, the landmark corners of the red diamond, this creates a more demanding search task than if the target possessed that critical feature (Treisman & Souther, 1985). Our pilot data also confirm that searching for a disc among diamonds is more difficult than searching for a diamond among discs.

Other factors also may have contributed to the difficulty of our simple-feature search task, for both young and older adults. In our hierarchical regression analyses we found that both near visual acuity and distractibility were significantly correlated with set-size effects. These results suggest that spatial resolution and the ability to ignore irrelevant information may be important factors in explaining why simple-feature search is not extremely easy.

The ability to resolve spatial details of objects is better for centrally viewed objects than for peripherally viewed ones (e.g., Davis, Yager, & Jones, 1987). To the extent that spatial resolution decreases as a function of visual-field eccentricity, this can affect simple-feature search performance (e.g., Carrasco, McLean, Katz, & Frieder, 1998). The visual array for set size 16 was a $4 \times 4$ matrix that extended over a square area of $8^\circ \times 8^\circ$, whereas for set size 36 the array was a $6 \times 6$ matrix that extended over a square area of $13^\circ \times 13^\circ$. Thus, the visual array extended more than 50% further into the peripheral visual field for the larger set size. For set size 36, at least some targets were presented at more eccentric locations than for set size 16. The poor spatial resolution at more eccentric locations could contribute to the set-size effects obtained in our study. At more eccentric locations it may be more difficult to distinguish a disc from a diamond. Consistent with this interpretation, our regression results show that near visual acuity is significantly correlated with set-size effects—individuals with worse spatial resolution also have larger set-size effects.

The ability to ignore or suppress distractors can facilitate search performance (e.g., Duncan & Humphreys, 1989). Conversely, individuals who are distracted by irrelevant information have more difficulty searching for a target amid distractors (e.g., Rabbitt, 1965). Increasing the number of distractors makes the search task especially difficult for those who cannot ignore the irrelevant distractor information. So, those who fail to ignore irrelevant information may have larger set-size effects than do those who can successfully suppress information from the distractors. Consistent with this interpretation, our regression analysis shows that the Stroop interference measures are significantly correlated with set-size effects—individuals who manifest greater distractibility also have larger set-size effects.

All of the above factors could predict significant set-size effects and shallower time–accuracy functions for the larger set size. But, we must also account for the improvement in search efficiency for the larger set size.

**If Simple-Feature Search Is Not Extremely Easy, Why Is Search Efficiency Better for the Larger Set Size?**

Although most of our results are consistent with the predictions shown in Table 2 for more difficult search, one piece of evidence is not: Search efficiency is better for the larger set size of 36 items, as predicted for extremely easy search. However, the relative improvement in search efficiency is less than predicted for extremely easy search for all participants.

To explain why search efficiency is better for the larger set size, we emphasize that search performance is not a dichotomy but instead is represented by a continuum from extremely easy to extremely difficult. Extremely easy search arises from noise-free, unlimited-capacity parallel processing in which all stimuli are completely and independently processed. At the other end of the continuum, extremely difficult search could occur because of serial processing in which only one stimulus is processed per unit time. Although some researchers have been strong proponents of a strict dichotomy between parallel and serial processing (e.g., Treisman & Gelade, 1980), more recently some of these researchers and others have accepted the concept of a continuum of search effort (e.g., Duncan & Humphreys, 1989; Treisman & Sato, 1990; Wolfe, 1999). Between the two extremes of parallel and serial processing, intermediate levels of difficulty could arise in searching for a target. For example, search could be more difficult because unlimited-capacity processing occurs, but the processing is noisy and sometimes a distractor is mistaken for a target (e.g., Davis & Peterson, 1998; Palmer, 1995; Shaw, 1980). Alternatively, search could be more difficult because of limited capacity in processing several stimuli simultaneously and independently (e.g., Davis & Peterson, 1998; Palmer, 1995; Shaw, 1980). Limited capacity implies that the available processing capacity is not sufficient to completely process all stimuli within the available time.
We consider two possible explanations of why search efficiency is better for the larger set size. Both explanations assume an intermediate level of difficulty in searching for the target. One emphasizes a change in perceptual grouping, resulting in an apparent increase in the capacity limitation for the larger set size. The other emphasizes spreading of suppression among similar distractors, which reduces the noise level for unlimited-capacity parallel processing.

Perceptual grouping strategy.—Typically, limited capacity is assumed to be fixed (e.g., only four items can be processed simultaneously), but it need not be. Qualitatively, our results are consistent with a larger capacity limitation for set size 36 than for set size 16.

Why should the capacity limitation be greater for the larger set size? One reviewer (R. Krampe, personal communication, December 2000) suggested that perhaps limited capacity is larger for set size 36 because the stimuli are arranged in a matrix of 6 × 6 items, whereas for set size 16 the stimuli are arranged in a matrix of 4 × 4 items. Suppose an observer processes the visual display row by row (e.g., Carrasco & Chang, 1995). In this case, items within a row are perceptually grouped together and any deviation in shape among those items would be readily apparent. For the larger set size the effective limited capacity would be six because there are six items within each row, whereas for the smaller set size the limited capacity would be four because there are only four items within each row. If so, search efficiency for set size 36 should change by a factor of .6666 (viz., 4/6). As shown in Table 4, this prediction is consistent with search performance for mid- and high-accuracy responses, but the relative improvement in search efficiency for low-accuracy responses is better than the hypothesis predicts.

Spreading of suppression.—Another possible explanation is based on extending Duncan and Humphrey’s (1989) research. Suppose that all items in the array can be processed in parallel, but the processing is noisy, and distractors sometimes are mistaken for targets. Duncan and Humphreys reported that homogeneous distractors produce very effective perceptual grouping and spreading of suppression among similar distractors so that the target is easily segregated from them. The perceptual grouping of distractors is based on the Gestalt principle of grouping by similarity. The spreading of suppression among the distractors reduces the noise level associated with individual distractors so that they are less likely to be mistaken for a target.

To understand why search efficiency is better for the larger set size, consider the following. Internal distractors that are surrounded on all four sides by other similar distractors receive more suppression than distractors that appear along the border of the display. A 4 × 4 array has 12 items along the border and four internal items. A 6 × 6 array has 20 items along the border and 16 internal items. Because an internal distractor receives more suppression, it also has a lower noise level than does a border distractor. As a result, an internal distractor is less likely to be mistaken for a target than is a border distractor. The larger set size has a larger proportion of internal distractors (16/36) than does the smaller set size (4/16). The net result is better search efficiency for the larger set size by a factor of .563, as shown in Table 4.

We show below that although the perceptual grouping hypothesis fits well with the older adults’ data, it does not fit the young adults’ data. Instead, the young adults’ data are more consistent with the spreading of suppression hypothesis. There are also other possible reasons for the differences between young and older adults’ search performance.

Why Is Simple-Feature Search More Difficult for Older Adults?

More difficult search requires additional time to process and extract the necessary visual information compared with easier search. One explanation of why search is more difficult for older adults is that they are slower in perceptually processing information. Several researchers have reported that older adults need more time to process visual information (e.g., Gottlob & Madden, 1998; Madden & Allen, 1991; Scialfa & Kline, 1988) unless the visual display is very simple (e.g., Salthouse & Sonberg, 1982). This claim fits well with an explanation of age-related changes based on either a proportional model of generalized slowing (e.g., Cerella, 1985, 1990; Salthouse, 1991) or a more sophisticated model of slowing (e.g., Cerella, 1990; Myerson et al., 1990).

Explaining age-related differences in relative set-size effects.—According to a proportional model of generalized slowing (Cerella, 1985, 1990; Salthouse, 1991), the SOA threshold durations for older and young adults should be related by a single factor (e.g., \( SOA_{\text{old}} = m \times SOA_{\text{young}} \), where \( m > 1 \)). Thus, the proportional slowing model does not explain why age-related differences occur even for relative set-size effects (viz., the ratio of SOA threshold durations for set sizes 16 and 36). It also cannot explain why the slope of the equal-accuracy state–trace function appears to be steeper for older adults than for young adults (see Figure 4). The steeper state–trace function suggests that searching through the larger set size is relatively more difficult for older adults than it is for young adults.

A more sophisticated model of slowing, such as Myerson and colleagues’ (1990) information-loss model, could account for the age-related differences in relative set-size effects. Myerson’s model claims slowing is caused by loss of information because processes performed with reduced information take longer. The model predicts that a constant proportion of the information is lost at each step along the way and the loss of information accumulates exponentially over the number of processing steps. Suppose that each step corresponds to a glimpse of the visual array in which a limited number of items are processed. If the visual array has a large number of items, it will require more glimpses to process the items in that array than if there were only a small number of items and, consequently, the information loss will be much greater for the larger set size. Older adults lose a larger proportion of information at each processing step than young adults do, so the age-related differences in processing time will be relatively larger for tasks with many processing steps than for tasks with fewer steps. As a result, older adults should have relatively larger set-size effects than young adults.
Explaining older adults’ worse search efficiency for high-accuracy responses.—For set size 36, most of the older adults’ search efficiency is worse for the high-accuracy condition than for the low-accuracy condition. Myerson and colleagues’ (1990) information-loss model also can explain why search efficiency is worse for high-accuracy performance. Table 3 shows that high-accuracy performance requires searching through a larger proportion of the items (.686 of the array) whereas searching through a smaller proportion of the items (.306) is sufficient for low-accuracy performance. With an array of 36 items, the observer must search through approximately 25 items for high-accuracy performance and through 11 items for low-accuracy performance. High-accuracy performance requires more items to be examined, so there are more glimpses or processing steps for the high-accuracy condition than for the low-accuracy condition and, thus, more opportunities for information to be lost. Because the loss of information accumulates exponentially with the number of processing steps, not only is the overall SOA threshold duration much longer, but also the search efficiency (average search time per item) is worse for the high-accuracy condition than for the low-accuracy condition.

No slowing model can explain why search efficiency is actually better for the larger set size of 36 items than for the set size of 16 items, even for older adults. All slowing models predict that search efficiency will be either the same or possibly worse for the larger set size. Other factors than age-related slowing must be involved.

Explaining age-related differences in relative improvement of search efficiency for larger set size.—Although search efficiency is better for the larger set size, the relative improvement is more modest for older adults than for young adults (see Table 4). One possibility is that the young adults have a more effective perceptual grouping strategy than do older adults. Another possibility is that both young and older adults have the same effective perceptual grouping strategy, but some other factor adversely affects older adults’ search efficiency.

Suppose that young adults can perceptually group and suppress irrelevant distractors better than older adults can. If so, young adults may use a different perceptual strategy than the older adults. The data in Table 4 suggest that older adults perceptually group and scan the visual array row by row or column by column, whereas young adults use a more efficient perceptual strategy. Young adults may be able to process simultaneously all items in the array, but the processing is noisy, and sometimes a distractor is mistaken for a target. For young adults, search efficiency improves for the larger set size because spreading of suppression is more effective in reducing the noise associated with individual distractors for the larger set size, as previously described. Madden and colleagues (1996) arrived at a similar conclusion when they compared young and older adults’ conjunction search performance. They had two search conditions, one in which the target was embedded among homogeneous distractors and one in which it was embedded among heterogeneous distractors. Homogeneous distractors improved search performance, but the relative improvement was larger for young adults than for older adults. They concluded that young adults could be better at perceptually grouping or suppressing the homogeneous distractors than older adults could. Our Stroop test results also are consistent with this interpretation; they showed that older adults have more difficulty suppressing irrelevant information than young adults do (see Table 1).

Another plausible explanation is that both young and older adults use the same efficient perceptual strategy. For example, both young and older adults may simultaneously process all items in the array using noisy, unlimited-capacity parallel processing. For both young and older adults search efficiency is better for the larger set size because of more effective spreading of suppression among the distractors for the larger set size. However, suppose older adults also suffer a greater loss in spatial resolution as a function of eccentricity in the visual field. If so, the relative improvement in search efficiency for the larger set size would be more modest for older adults than for young adults. Our near visual acuity results are consistent with this interpretation; they showed that older adults have worse spatial resolution than young adults (see Table 1).

Conclusion

In summary, when we used a procedure that emphasized perceptual processing and deemphasized decision-making and psychomotor processing, we found that simple-feature search for a disc among diamonds was more difficult for older adults than for young adults. Older adults required more time than young adults to extract perceptual information, as predicted by age-related perceptual slowing. However, a simple proportional slowing model cannot explain why older adults have relatively larger set-size effects; nor can it explain why their search performance is so much worse for high-accuracy responses. Instead, a more sophisticated slowing model, such as Myerson and colleagues’ (1990) information-loss model, is needed to explain these age-related differences in search performance.

No slowing model can explain why search efficiency is actually better for the larger set size, even for the older adults. Strategies based on perceptual grouping or on the suppression of irrelevant distractors could account for the improvements in search efficiency. Both strategies represent an intermediate level of search difficulty. Our results are consistent with young adults using the more effective suppression strategy and older adults using the perceptual grouping strategy, perhaps because older adults fail to suppress irrelevant information or have perceptual-capacity limitations. Alternatively, older adults may have used the same perceptual strategy as young adults, but the strategy is less effective for the older adults because their performance is adversely affected by other factors, such as poor spatial resolution. In the future we would like to further investigate these alternative explanations and systematically examine other shape combinations and stimulus dimensions, such as size and color.

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