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Aging and the Development of Automaticity in Visual Search

David J. Madden and Robert D. Nebes
Center for the Study of Aging and Human Development
Duke University Medical Center

The rate of short-term memory search has previously been reported to be slower for older individuals than for college-age subjects. Current research has suggested that after extensive practice with the same population of stimuli, performance in memory-search and visual-search tasks can become "automatic," or independent of memory load. The present experiment examined age differences in the development of automatic processing in a hybrid memory-search/visual-search paradigm; eight young (*Mdn* age = 22.0 years) and eight older (*Mdn* age = 67.5 years) subjects participated. Although the older subjects demonstrated a significantly slower rate of search, the two age groups shifted toward automatic processing, over practice, at equivalent rates. The slower rate of search thus represents an age-related increase in the time required to compare the memory-set items against those in a visual array, rather than a change in the mode of processing available.

Studies of perceptual and memory functioning in young adults have often relied on analyses of the time subjects require to make certain decisions about visual stimuli. For example, one type of paradigm that is frequently used to investigate the memory processes involved in visual identification is the binary-classification task, in which subjects must decide whether or not two sequentially presented arrays of characters possess any items in common (Nickerson, 1972). Sternberg's (1966, 1967) landmark investigation of character recognition is a version of binary classification that requires subjects to make a *yes/no* decision regarding the presence of a single test item (or probe) in a previously memorized set of target items. Sternberg found that reaction time (RT) to the visually presented probe was an increasing linear function of memory-set size (M) for both yes and no responses. This suggested that the subject's classification decision depended on a serial (i.e., item-by-item) search through the targets in short-term memory. The slope of the linear RT function could then be used as an estimate of the rate of comparison between the probe and target items, since the slope is the average increase in RT for each additional member of the memory set. Similarly, the intercept of this function represents the time required to encode the probe and mobilize a response, exclusive of comparison, since the intercept is an estimate of the RT associated with a memory-set "size" of zero. Although many issues regarding the nature of memory search are unresolved, there is substantial converging evidence that the slope and intercept measures are valid estimates of the different stages involved in performing the memory-search task (see Chase, 1978; Sternberg, 1975).

It has been noted that older subjects (i.e., those in their 60s and 70s) show performance decrements in memory tasks relative to college-age subjects, especially when the processing limitations of short-term mem-

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Requests for reprints should be sent to David J. Madden, Center for the Study of Aging and Human Development, Box 2980, Duke University Medical Center, Durham, North Carolina 27710.

ory are exceeded (for a review see Craik, 1977). Yet even when the number of items to be remembered does not exceed the memory span, age differences in the speed of memory retrieval have appeared. For example, work with the Sternberg paradigm has shown that the slope as well as the intercept of the RT function are increased in older adults, suggesting an age-related slowing in both encoding/response processes and in the rate of memory search (Anders & Fozard, 1973; Anders, Fozard, & Lillyquist, 1972). Using a related paradigm, Gaylord and Marsh (1975) found that the rate of "mental rotation" of nonverbal stimuli was slower for older subjects.

However, it is important to distinguish age differences that are related to specific aspects of task performance from those that may be due to a nonspecific slowing of cognitive function; and according to Shiffrin and Schneider (1977), there are two qualitatively different modes of performance that contribute to the results of memory-search tasks. The first is termed *controlled search*; this is an attention-demanding, serial comparison of information in short-term memory and is reflected in the positive slope values typically obtained in search tasks. Controlled search is easily established and altered by the subject, but the level of performance is highly dependent on processing load, that is, on the number of items to be compared. *Automatic detection*, on the other hand, is parallel in nature (i.e., comparisons are made simultaneously) and involves the direct activation of target identity in long-term memory as a result of stimulus presentation. Automaticity is difficult to acquire and, once established, difficult to alter, but it is independent of processing load. The controlled/automatic distinction is relevant to visual-search tasks (in which M is typically one item, and the number of characters in the probe display varies) as well as to memory-search tasks (in which M varies, and there is only one probe item per trial). There is considerable evidence suggesting that memory search and visual search actually share the same processing stage of target-probe comparison (e.g., Briggs & Blaha, 1969; Johnsen & Briggs, 1973).

Shiffrin and Schneider (1977) reported a series of experiments from which they conclude that whether subjects are engaged in controlled or automatic processing depends on the type of stimulus–response "mapping" present in the search task. "Consistent mapping" occurs when the same set of stimuli are used as target items across trials, so that whenever one of these stimuli appears, it requires the same response. "Varied mapping" is present when particular stimuli appear as both target and nontarget (or distractor) items across trials. Shiffrin and Schneider claim that varied mapping leads to the adoption of controlled search and thus to RT values that increase linearly over M. Under varied mapping conditions, the rate of memory search (as indexed by the slope value) does not substantially change over extensive practice (Kristofferson, 1972). Consistent mapping, on the other hand, leads to the development of an "automatic-attention response" to the targets and to RTs that are independent of processing load (i.e., constant over M). After extensive practice, the presentation of a consistently mapped target stimulus will automatically attract attention to this item's features, so that the need to search among the other items of the memory set is bypassed entirely. Thus, practice with consistently mapped stimuli leads to slope values that are either greatly reduced or reach zero (Logan, 1978, Experiment 1; Ross, 1970; Schneider & Shiffrin, 1977, Experiment 2).

The present study was undertaken to determine whether the age differences that have previously appeared in search tasks represent either a nonspecific increase in the time required by the mental operations involved in this task or a change in the specific modes of processing available. For example, the increased slope values could reflect a tendency for older subjects to always rely on a controlled processing strategy in search tasks, whereas young subjects would have both controlled and automatic processing available. Any deficit in the ability to develop automatic detection would have put older subjects at a particular disadvantage in the "secondary memory" condition of the Anders and Fozard (1973) study, since the particular target items in this condition remained constant over testing.

In the present experiment, both young

and older subjects were given extensive practice (2,592 trials) with consistently mapped target and distractor stimuli. The task was a hybrid memory-search/visual-search paradigm in which the memory set contained one, two, or three target letters, and the probe display was always two simultaneously presented letters. This task was chosen because Schneider and Shiffrin (1977, Experiment 2) found that under similar conditions highly practiced subjects demonstrated automatic detection (i.e., zero slope values). The present task could serve to extend previous reports of age differences in memory search (Anders & Fozard, 1973; Anders et al., 1972) to a situation requiring subjects to search a probe display containing more than one item. The question of primary interest, however, was whether the development of automatic detection, as defined by the decrease of slope values over practice, would be more pronounced for the young than for the older subjects. As an additional check on the presence of automaticity, subjects were given completely new stimulus sets in the final experimental session.

Method

Subjects

Eight young and eight older individuals were paid participants in the experiment; there were four males and four females in each age group. The young subjects were Duke University undergraduates and technical staff members of the Duke University Medical Center, ranging in age from 18 to 25 years (*Mdn* = 22.0). The older subjects were selected from the Duke Aging Center subject pool, a group of over 700 community-dwelling adults. The older subjects in the present study ranged in age from 61 to 74 (*Mdn* = 67.5). The young subjects were attending or had completed college; all of the older subjects had completed college. Both the young and older subjects possessed corrected visual acuity of at least 20/30 and had previous experience in performing tachistoscopic tasks.

Apparatus and Stimuli

On each trial, subjects searched a visually presented two-letter array for the presence of a target letter. The stimulus arrays were presented via a Scientific Prototype three-channel tachistoscope in which the luminance level was set at approximately 55 cd/m^2. The stimuli were black uppercase letters (Chartpak Futura, demibold, 36 pt) mounted on white tachistoscope cards, and the two letters of each array were arranged vertically in the center of a card. Each letter subtended about .5° × .5° at a viewing distance of 91.4 cm; the inner edges of the two letters were separated by .75°. Exposure duration of each array was 200 msec. Subjects viewed the stimuli binocularly and indicated their decisions by moving a paddle switch mounted on a board in front of the tachistoscope. Each subject used his or her preferred hand throughout the experiment. Movement of the switch from a central position stopped a digital clock that had begun running at the onset of the array. Half of the subjects in each age group moved the switch toward themselves for a *yes* (i.e., target present) decision and away for *no*, and half had the reverse arrangement. Subjects were tested individually and performed the experiment in 10 sessions of approximately 45 min each on 10 successive days. No subject performed more than 1 session per day or had more than one weekend break in the series. All subjects performed Sessions 9 and 10 on consecutive days.

Over the first 9 experimental days, consistent mapping was maintained, in that the populations of target and distractor letters composing the arrays remained constant. The target letters were the consonants K, C, Z, S, N, and G, and the distractors were M, D, V, B, X, and P. On each day, subjects performed 288 trials in nine blocks of 32. A "fixed set" procedure was adopted in which subjects searched for a specific memory set of one, two, or three of the target letters in a trial block. Targets presented in a trial block were drawn only from the memory set associated with that trial block, and subjects were aware of this fact. On a positive trial only one of the target letters was actually present in the two-letter array, and targets were equally distributed between the upper and lower items of the array within a trial block. On a negative trial, two different distractors were always present in the array. Each block contained 16 positive and 16 negative trials, which were randomly ordered with the constraint that a particular decision type not appear more than four times in succession. Each experimental day was divided into three sections, each containing one block of every set size.

Two different lists of arrays, each containing nine blocks of experimental trials, were constructed for use on Days 1–9. Target letters were randomly distributed over memory-set size (M) with the constraint that across both lists, each of the six target letters appeared once for M = 1, twice for M = 2, and three times for M = 3. Across the positive trials of the two lists, each of the six target letters appeared eight times as the upper item of an array, and eight times as the lower item, for each value of M. Each of the six distractor letters was similarly distributed across these arrays. On the negative trials, each of the distractor letters appeared a total of 16 times at each of the positions in the array at each value of M. Within each block of the two lists, the individual target and distractor items were distributed as equally as possible. Subjects were given these two lists in an alternating sequence over days; as a check on the possibility that subjects learned the trial sequence of the individual lists, the appropriate list was presented in a reverse order on Day 9. On the 10th day, subjects were required to perform the same visual-search task with new populations of targets and distractor letters. The new targets were F, Q, T, and H, and the distractors

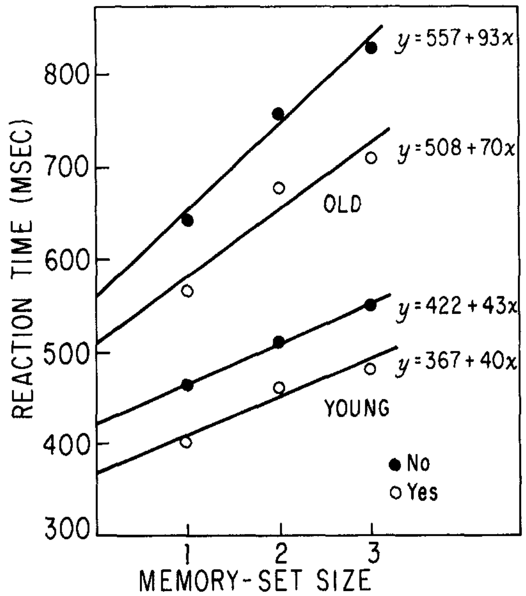

Figure 1. Mean reaction time as a function of memory-set size, averaged over the first 9 experimental days, with best fitting linear equations. (The two trial types—*yes*, *no*—and two age groups—old, young—are plotted separately. Each point in the graph is based on 3,456 observations.)

were J, L, R, and W. As on Days 1–9, the targets and distractors were consistently mapped onto positive and negative responses, and subjects searched for one, two, or three targets in each trial block. A single list of 288 trials was constructed containing three blocks of each of the three M values. The individual targets were assigned to the memory sets, and the individual blocks counterbalanced, in a manner similar to that of the first two lists.

Procedure

On the first experimental day, subjects read instructions that described the visual-search task (including the nature of the consistent mapping) and defined the target and distractor letters for the first 9 days. The instructions stated that accuracy and speed were equally important. At the beginning of each subsequent day, subjects were required to correctly recall all of the target letters from memory and were permitted to review them if necessary. The same procedure was followed on Day 10, when subjects were instructed to perform the same task with new target and distractor letters. At the beginning of each block of experimental trials, subjects were shown the appropriate memory set and were permitted to examine it as long as they wished. No practice trials were given. Each trial consisted of the following sequence of events: the experimenter advancing a new stimulus array; the appearance of a central fixation dot, positioned between the locations of the subsequent two letters, for 1 sec; and the exposure of the two-letter array for 200 msec, followed by the subject's response. The motor of the stimulus card changer provided an audible signal of the presence of a new trial. During the interval between the offset of the array and the onset of the fixation dot, the area in which the letters appeared was filled by a pattern mask of overlapping letter segments.

Results

The Memory-Set Size Functions

To characterize the relation between mean RT and memory-set size (M), an analysis of variance (ANOVA) was performed for the first 9 days of practice, with RT as the dependent variable. Age (old, young) was a between-subjects factor; M (1, 2, and 3) and trial type (yes, no) were within-subjects factors. The .05 level of significance was adopted. All three main effects were significant: There was an increase in RT over M, $F(2, 28) = 287.28$, $MS_e = 2{,}184.81$, and longer RTs were observed for the older subjects, $F(1, 14) = 39.75$, $MS_e = 143{,}729.43$, and for the *no* trials, $F(1, 14) = 215.26$, $MS_e = 3{,}339.93$. The Trial Type × M, $F(2, 28) = 5.82$, $MS_e = 1{,}644.58$, and Age × M interactions, $F(2, 28) = 31.50$, $MS_e = 2{,}184.81$, were significant. That is, the increase in RT over M was relatively greater for the older subjects and was greater on the negative trials than on the positive trials. The Age × Trial Type interaction, $F(1, 14) = 10.48$, $MS_e = 3{,}339.93$, was also significant, which resulted from the fact that the difference between the yes and no trials was relatively greater for the older subjects. The relatively greater RT on the no trials shown by the older subjects may represent a more cautious decision criterion, since their false alarm rate was slightly less than that of the young subjects (see Table 1). However, the Age × Trial Type × M interaction was not significant ($p > .10$). Trend tests demonstrated that for each age group, at least 96% of the variance associated with the set-size effect was accounted for by a linear trend. The relation between RT and M was thus assumed to be primarily linear. The observed mean RTs, averaged over practice, and best fitting linear equations are presented in Figure 1.

Errors. The RT of incorrect responses was not included in the analysis. Mean false alarms was less than 2% for both age groups. Young subjects missed the presence of a target on an average of 3.26% of the positive trials; older subjects averaged 3.12% misses. The pattern of errors is presented in Table 1, and this pattern does not suggest that the Age × M interaction obtained for RT is the result of a speed–accuracy trade-off.

Table 1
Mean Percentage of Misses and False Alarms by Age Group and Memory-Set Size for Days 1–9 and 10

	Memory-set size for misses			Memory-set size for false alarms		
Age group	1	2	3	1	2	3
Young						
Days 1–9	1.87	4.63	3.27	1.58	1.89	1.42
Day 10	2.34	5.73	5.99	1.56	2.34	1.30
Old						
Days 1–9	2.00	3.40	3.95	.72	.77	.93
Day 10	2.86	4.17	4.69	.52	.52	.78

Slope and Intercept Analyses

The slope and intercept of the linear increase in RT over M were obtained for each subject in each experimental condition. To increase the reliability of the slope and intercept measures, the first 8 days of consistent mapping were grouped into four sets, each containing the mean RTs over 2 successive days. The RTs on Day 9 (which involved a new trial sequence) and Day 10 (which involved a new population of targets) were not averaged, however. Thus, in terms of the analysis, there were five sessions of practice with the same target and distractor letters (i.e., Days 1 and 2, 3 and 4, 5 and 6, 7 and 8, and 9), and one session of practice with new targets and distractors (Day 10). A multivariate analysis of variance (MANOVA) was then employed to assess the change in the slopes and intercepts over practice with the same target population. The independent variables included the between-groups factor of age (old, young) and the within-groups factors of trial type (yes, no) and session (1–5). The multivariate F value for each statistical effect was based on a Hotelling-Lawley trace, and the .05 level of significance was adopted.

In the analysis of slopes and intercepts, significant multivariate F values were present for the main effects of age, $F(2, 13) = 21.13$; trial type, $F(2, 13) = 131.07$; and session, $F(8, 108) = 35.90$. Two of the interaction effects were significant: Age × Trial Type, $F(2, 13) = 4.88$, and Trial Type × Session, $F(8, 108) = 2.46$.

Slopes. An ANOVA performed on the slope values revealed that the main effects of age, $F(1, 14) = 31.21$, $MS_e = 2{,}066.79$, and session, $F(4, 56) = 51.51$, $MS_e = 297.46$, were significant. The older subjects exhibited a slower rate of visual search than the young subjects, but the search rate of both age groups became significantly faster over sessions. The trial type main effect, $F(1, 14) = 5.00$, $MS_e = 1{,}301.57$, and the Trial Type × Session interaction, $F(4, 56) = 4.60$, $MS_e = 143.61$, were significant, resulting from the fact that although the slope of the no trials was initially higher than that of the yes trials, this difference decreased over the course of practice. Contrary to expectation, the Age × Session interaction was not significant for the slope variable, indicating that the two age groups benefited equally from practice with consistently mapped targets. Changes in the slope values over sessions are presented in Figure 2.

Subjects in the present experiment apparently reached an asymptotic level of search rate between Days 7 and 9 (i.e., between 1,728 and 2,592 trials). An ANOVA performed on the individual slopes of Days 7, 8, and 9 (without averaging) yielded neither a main effect of day nor any interaction of day with age or trial type.

Intercepts. In the ANOVA of the intercept values, only the main effects of age, $F(1, 14) = 22.80$, $MS_e = 33{,}338.30$, session, $F(4, 56) = 12.74$, $MS_e = 1{,}448$, and trial type, $F(1, 14) = 31.42$, $MS_e = 3{,}430.30$, were significant. As can be seen in Figure 3, the older subjects required more time than the younger subjects to encode the array and organize a response. Both age groups exhibited lower intercept values on the yes

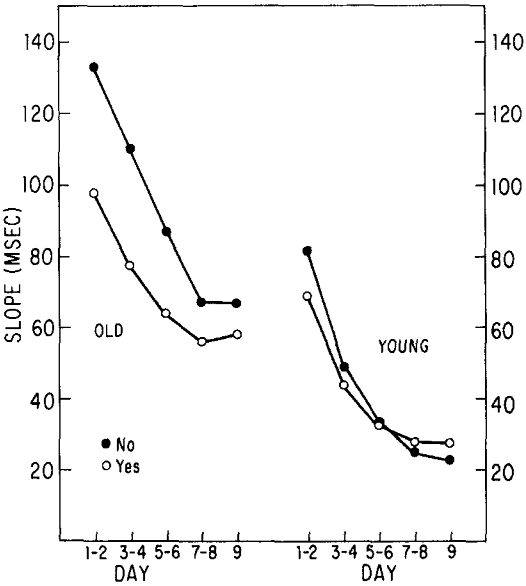

Figure 2. Mean slope value as a function of practice with the same population of stimuli. (The two trial types—*yes*, *no*—and the two age groups—old, young—are plotted separately.)

trials; this result is usually obtained in visual comparison tasks and may reflect the fact that yes and no responses are mediated by different processes (see Nickerson, 1978). The encoding and response time of both age groups significantly improved (i.e., decreased) with practice. As was the case with the slope values, the rate of this improvement over the sessions was equivalent for the young and older subjects.

Days 9 and 10

The effect of presenting a new population of targets and distractors in the final session was examined by a separate MANOVA for the slopes and intercepts on Days 9 and 10. Significant multivariate *F* values were obtained only for the effects of age, $F(2, 13) = 18.95$, session, $F(2, 13) = 23.62$, and trial type, $F(2, 13) = 75.75$. The ANOVA of the slope values showed a significant age effect, $F(1, 14) = 26.46$, $MS_e = 720.38$, with the young subjects retaining their advantage in the rate of search that was present in the earlier sessions. More importantly, there was a significant effect of session, $F(1, 14) = 42.30$, $MS_e = 379.36$, and the search rates of both age groups were slowed by the substitution of a new population of targets on the final experimental session. The mean slope value of the older subjects rose from 63 msec to 91 msec across Days 9 and 10, whereas the young subjects' slope increased from 25 msec to 60 msec. By the criterion of zero slope, even the young subjects in the present study had not completely developed automatic detection, since their average slope on Day 9 was approximately 25 msec per item. However, both the reduction of slope over practice and the increase in slope associated with the new targets argue that the development of a substantial amount of automaticity had occurred.

Univariate tests on the intercept values of the final two sessions revealed significant effects of age, $F(1, 14) = 14.90$, $MS_e = 11{,}739.29$, and trial type, $F(1, 14) = 48.45$, $MS_e = 1{,}172.97$, that were consistent with those obtained for Sessions 1–5. Paradoxically, the intercept values were significantly *lower* on the final session, $F(1, 14) = 38.22$, $MS_e = 701.28$, even though the slope values were higher. This pattern of results occurred because the RT for M = 2 and M = 3 increased with the presence of the new stimuli, whereas M = 1 RT remained

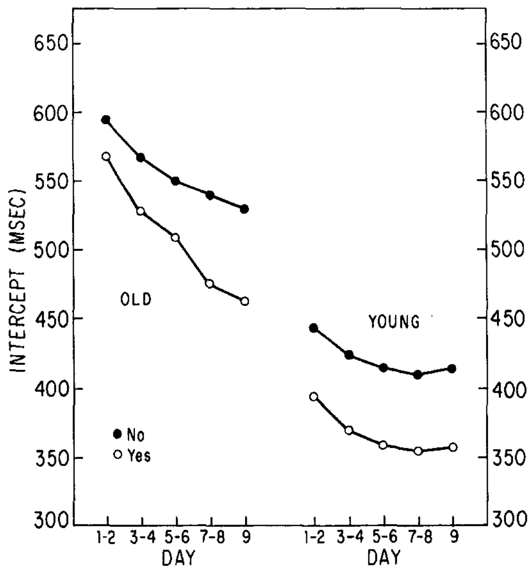

Figure 3. Mean intercept value as a function of practice with the same population of stimuli. (The two trial types—*yes*, *no*—and two age groups—old, young—are plotted separately.)

virtually constant over the last two sessions. Thus, although the RT increase on the final session was reflected in the slope values, the intercepts were artificially lowered.

Discussion

In the present visual-search task, subjects given extensive practice with consistently mapped targets showed a significant development of automatic processing, as predicted by the Shiffrin and Schneider (1977) theory. For both young and older subjects, the slope of the RT function over M decreased over the course of practice, reached an asymptotic level between the 7th and 9th experimental days, and then increased when a new group of targets was presented on the 10th day. Yet even though the dependence of decision RT on M was reduced with practice, the zero slope value obtained by Schneider and Shiffrin (1977, Experiment 2) was not obtained here. One methodological difference between the present experiment and that of Schneider and Shiffrin is the fact that they used targets and distractors that were categorically distinct (consonants and digits), whereas our targets and distractors were both drawn from the same category (consonants). When such a categorical distinction is not available, subjects may thus require more extensive practice before a complete independence between decision RT and memory load can be achieved. Since the slope values of the present study continued to decrease until Days 7, 8, and 9, it is possible that at least the young subjects, given more training, could have eventually reached the criterion of zero slope. On the other hand, Logan (1978) has noted that zero slope values are rarely achieved in search tasks and has suggested that there are different *forms* of automaticity, one of which is reflected in slope values that reach zero. We believe that certain relationships among the stimuli used in a search task, such as a difference in category between targets and distractors (in addition to consistent mapping), may be a necessary condition for subjects to demonstrate zero slope, but this remains to be determined.

The results of the present study agree with previous research (Anders & Fozard, 1973; Anders et al., 1972) that has demonstrated an increased slope for older subjects in tasks requiring memory search. Interestingly, the size of this age difference is consistent across studies, and in each case the older subjects' rate of search is approximately double that of the young. In the Anders et al. (1972) data, the ratio of the slope values of the older subjects to those of the young is 1.82; the analogous ratio from Anders and Fozard (1973) is 1.96. In the present experiment, the old/young slope ratio, averaged over the first 9 days of practice, is 1.97, reflecting a significant increase in the time required by the older subjects for comparing the target and array items. In addition, a significant age difference in the intercept of the RT function was shown by the present subjects, a result that is also consistent with previous findings. For example, recent studies of backward masking in vision have demonstrated that older subjects require more encoding time in stimulus identification (e.g., Walsh, Till, & Williams, 1978), and the increase in motor response time associated with age is well documented (e.g., Birren, 1965).

In spite of the substantial age differences in the slope and intercept values noted above, these differences did not extend to the specific performance strategy elicited by the present task. Contrary to our initial hypothesis, the two age groups did not differ in the rate at which the slope values decreased over practice, that is, in the rate at which automaticity developed (see Figure 2). The two age groups of the present study were also equally affected by the presentation of new stimuli on the final day. The only hint of an age difference in processing strategy was an Age × Trial Type interaction, which appeared in the univariate analysis of M functions. This interaction also appeared in the multivariate analysis, although it was not significant for either the slopes or the intercepts independently. The age differences observed in the present task thus reflect a nonspecific increase of information-processing time with age rather than a change in the mode of processing available. This RT increase is not simply an artifact of changes in motor response time, since the slope is an estimate of comparison rate that is theoretically independent of peripheral factors (see Sternberg, 1975). There are also some experimental situations, such as sentence-formation tasks (Nebes & Andrews-Kulis, 1976), in which older subjects have been observed to respond just as rapidly as the young. Consequently, even though the age-related increase in processing time observed here was not strategy specific, the evidence suggests that it is closely related to the class of cognitive operations involved in memory search and visual search.

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