Age and visual search: expanding the useful field of view

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The useful field of view is defined as the visual area in which information can be acquired within one eye fixation. We studied visual search within this context and found a reduction in the size of the field as a function of age. This loss, however, was recovered partially with practice. Standard acuity and perimetric tests of visual field, although diagnostic of disease, underestimate the degree of difficulty experienced by visually healthy older adults in everyday activities requiring the use of peripheral vision. To aid in predicting such performance, a model incorporating the effects of distractors and secondary task demands was developed.

INTRODUCTION

The detection, localization, or identification of an object in the visual field can be a complex process. Under everyday conditions, young adults are usually not aware of this complexity, performing most visual tasks effortlessly despite the diversity of stimuli present in the visual field. Visually healthy older adults, however, are more likely to report difficulty with situations involving visual distractors, or clutter, and with other activities requiring the use of peripheral vision, such as driving and mobility in general.[1] The purpose of this study was to examine systematically how aging and practice affect the extent of the peripheral field within which a target can be localized, while manipulating several variables that make this task difficult for older observers. A long-term goal was to determine the bases for age-related decrements in visual processing as well as for improved performance after practice and to gain a better understanding of how these changes affect the functional vision available to older adults on a daily basis.

Although there is good evidence for an age-associated decline in visual field extent and sensitivity in studies in which both standard (Goldmann) perimetry and automated perimetry are used,[2–8] these clinical measures are not predictive of the degree of difficulty that these older adults report with everyday activities such as driving, mobility, and visual search and of the slowing of visual processing.[9] This may be due to the fact that clinical perimetry measures the detection of a luminance target presented in isolation, whereas everyday activities, such as driving, usually require responses such as localization or identification of suprathreshold targets in cluttered visual scenes as well as the simultaneous use of both foveal and peripheral vision.

Statistics of driving accidents were compared with both visual field measurements and age in several studies. Older drivers, in general, were found to have disproportionately more accidents and cited traffic violations,[10,11] and their accident profiles include indications that they are having difficulty processing information from the periphery (i.e., failures to heed signs, to yield the right of way, and to turn safely and more-frequent junction accidents).[12–14] Even so, in most studies no link was found between age-related visual field loss, as measured by clinical perimetry, and driving performance.[15–18] Although in a recent large-sample study (N = 10,000) a relationship was found between accident rates and severe binocular visual field loss,[19] in this study a relationship was not found between age-related visual declines in otherwise visually healthy older adults and driving performance. In another study, however, a relationship was found between driving accident rates and performance in visual tasks incorporating visual clutter.[20] These results suggest that assessment of peripheral vision under more-realistic conditions may better predict the driving performance of older individuals.

Such visual field assessments were defined as measures of the functional, or useful, field of view (UFOV).[21] The UFOV is the total visual field area in which useful information can be acquired without eye and head movements (i.e., within one eye fixation). Measures of this field typically involve the detection, localization, or identification of targets against more-complex visual backgrounds. From this definition, the size of the UFOV has been found to vary substantially across situations and individuals.

The mere presence of a foveal stimulus was shown to reduce the UFOV.[22] Detection or localization of a peripheral stimulus can be impaired even further by creating an increased central task demand.[23–25] Another factor that influences the extent of the UFOV is the context within which the target is embedded. In general, performance on a variety of visual search tasks was found to suffer with the addition of background distractor stimuli to the display.[25,26] Both the number of distractors[27] and the similarity between target and distractor stimuli[28–32] were found to affect the degree to which distractors impair performance. Indeed, it was shown that the diameter of the area that can be searched in parallel (i.e., the diameter of the UFOV) is related directly to the similarity between a target and its embedding context.[31] Targets that differ from nontargets in many features, or textons (i.e., color, orientation, width, length, disparity, ends of lines, crossings of line segments), are conspicuous against their background context and hence are detected easily. As the conspicuity of the target increases, the area that may be examined in one fixation (the UFOV) also increases.

The UFOV was measured specifically as a function of age in several studies. Age-related declines in the extent of this field were found for extrafoveal acuity,[33] for letter identification,[27] and for radial localization[25] with targets embedded in

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distractors. It was also shown that, when targets are presented in isolation for brief durations, the addition of a secondary central task has a much greater effect on the peripheral performance of older observers.[34] Thus there is substantial evidence that the effects of both secondary tasks and distractor stimuli are much greater for older adults, especially at greater eccentricities.

In agreement with these laboratory studies, survey results indicated that the frequency of difficulty that older adults report on everyday tasks associated with peripheral vision, visual search, and cluttered visual scenes is about five times greater than that reported by younger adults.[1] Several authors suggested that a constricted UFOV may be responsible for these reports.[9,25,27,33] Even though we have unlimited viewing time in many daily situations, a constricted UFOV could affect performance by forcing the observer to perform more fixations in order to scan the same visual area. Given an age-related increase in the latency of ocular movements,[35] this would place older observers at a disadvantage in everyday situations involving visual search.

In an attempt to mimic these difficult visual situations for older adults, Sekuler and Ball[25] designed a radial localization task that measured how well a single, randomly positioned target could be localized in the presence of distractors both with and without a secondary center task. They found that age differences were greatest at increased retinal eccentricities, indicating a restricted UFOV for the older adults. Even though, in general, older observers exhibit this restricted UFOV effect, there is a great deal of variability in performance among older observers on this task. Performance on the task was found subsequently to be predictive of the frequency with which older individuals report difficulty with everyday activities involving their peripheral vision.[9] Furthermore, the performance of older adults was found to improve with practice on the task,[25] thus demonstrating the potential for reversing some of the age-associated decline.

Given evidence that the UFOV is not static and that any systematic expansion of this field is of both practical and theoretical significance, in the present study we examine the effects of training on a similar radial localization task. Four variables known to influence the size of this field are investigated: age, distractor number, center task demand, and eccentricity. Specifically, we measured radial localization performance for three levels of distractor number (density) and three levels of center task demand, for observers in three age groups. In the original study,[25] only the subjects in the oldest age group practiced the localization task at eccentricities of 5°, 10°, and 15°. In order to evaluate the effect of practice on young and middle-aged observers as well, it was necessary to extend the stimuli to 30°, at which point the youngest group could not achieve perfect performance. Training consisted of 5 days of practice with feedback. Follow-up examinations were conducted for a period of 6 months to determine the longevity of improved localization performance.

EXPERIMENT 1

Observers

Twenty-four observers participated in this experiment. Eight were classified as young (age range, 22–33 years; mean age, 25 years), eight were classified as middle aged (age range, 40–49 years; mean age, 45 years), and eight were classified as older (age range, 60–75 years; mean, 69 years). Written informed consent was obtained from each participant after the nature and purpose of the study were explained. Younger and middle-aged adults were in good ocular health, as indicated by their most-recent eye examination results. Mean letter acuity for each eye was 20/20 or better as assessed by the Bailey–Lovie charts (distance and near).

All older observers were living independently in the Bowling Green area and were in good general health. For the purposes of this study they underwent detailed ophthalmological examinations, which included direct and indirect ophthalmoscopy, biomicroscopy, applanation tonometry, and refraction for near and far distances. Intraocular pressure was found to be within normal limits (<20 mm Hg). All older adults were reported to be in good eye health, although they did exhibit the increased lens density typical of older age. The mean letter acuity for each eye was 20/25 or better. The average binocular near acuities (minimum angle resolvable) for the three age groups were 0.70, 0.75, and 0.96 arcmin. The acuity of the oldest age group, while quite good, differed significantly from that of the two younger age groups [$F = 14.02$; degrees of freedom (df) = 2, 21; $p < 0.01$]. Each observer wore his or her best optical correction during testing.

Stimuli

Every trial consisted of four successive computer-controlled displays presented on a large CONRAC video screen (60° × 60° at a viewing distance of 28.5 cm) with white phosphor. The first display, a bright outline box (8° × 9°), directed the observer's fixation. One second later, the test stimulus appeared with the fixation box for 90 msec. This presentation was too brief for observers to initiate and complete a shift in fixation during the test interval. After the test stimulus, spatially random masking noise (consisting of vertical and horizontal lines of varying intensity) was presented for 750 msec to obliterate any residual afterimages on the screen. Finally, a radial pattern appeared with eight equally spaced spokes, each labeled with a digit from 1 to 8. The spoke pattern remained visible until the observer selected one of eight numbers on a keypad located in front of him or her indicating the radial position of the test stimulus.

A schematic diagram of the test stimulus is shown in Fig. 1. This stimulus contained two components: (1) a central component presented in the fixation box, and (2) a peripheral component presented outside the fixation box. The peripheral test stimulus consisted of a cartoon likeness of a smiling human face subtending 3.0° × 6.0°. The luminance of this face was 2 cd/m^2. The background luminance of the screen was low (0.03 cd/m^2). Although such levels are below many encountered in everyday conditions, it was shown previously that radial localization is, within broad limits, not affected by luminance level.[36] The face appeared unpredictably but equally often in each of 24 different peripheral locations along one of eight radial spokes (four cardinal as well as four oblique) and at one of three eccentricities: 10°, 20°, or 30°.

All test and training conditions are listed in Tables 1 and 2. There were three distractor conditions. Under one condition the test stimulus appeared without distractors. Un-

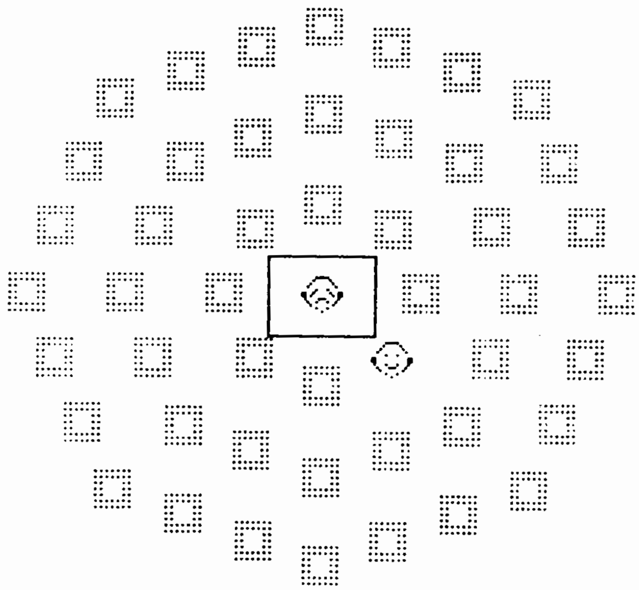

Fig. 1. Schematic representation of the type of stimulus used in the UFOV task. A frowning face is shown in the fixation box, and a peripheral target 10° from fixation is presented among 47 box distractors.

der the second condition (the full-distractor condition) the face target was accompanied by 47 outline boxes of the same size and luminance as the face itself. These boxes, or distractors, occupied all possible face positions as well as positions between the eight radial spokes in order to fill the screen. Under the third condition (the half-distractor condition) distractors were present in only the 23 potential target positions not occupied by the peripheral face (on only the eight spokes).

In addition to responding to the peripheral stimulus, observers were also required to respond to a concurrent central task presented in the fixation box. Under one condition (lowest demand), an additional cartoon face, the same as the one presented peripherally, appeared in the center of the fixation box 50% of the time. Observers were required to press one of two keys depending on whether the center face was present or absent. Under another condition (intermediate demand), the center face appeared on every trial, and the observer was required to identify the expression on the face (either smiling or frowning). The upward (downward) angle of corners of the mouth in the smiling (frowning) face was 45°. Under the third condition (highest demand), two faces appeared in the fixation box, and the observer was required to indicate whether the two faces had the same or different expressions.

Procedure

Each observer viewed the display binocularly at a test distance of 28.5 cm with his or her head positioned in a chin rest. A keypad, consisting of two labeled buttons for the center task response and eight buttons positioned radially for the peripheral task response, was located on a table directly in front of the observer. The observer made two responses at the end of each trial. The first response was made to the center stimulus (present or absent, smile or frown, or same or different), and the second response consisted of selecting the radial location of the peripheral face. Although we could have asked observers to indicate both the radial location and the eccentricity of the target, pilot data collected on this task indicated that when observers knew the correct radial position they also knew the correct eccentricity (>90% of the time for each observer). When observers did not know the correct radial position, the correct eccentricity was reported much less frequently (at approximately chance, or one third of the time). We thus decided to require only the radial position response in the peripheral localization task. Computer-generated tones provided immediate feedback about response correctness. If the response to the foveal stimulus was incorrect, then the trial was terminated and represented again some time later within the block of trials.

Trials were grouped in sets of 24 (with the peripheral face at each of its 24 possible positions). The order of testing of the various conditions was randomized for each observer. All observers were initially tested under all three distractor and center task conditions. This combination of task demand and distractor conditions resulted in pretraining measures under nine conditions per observer.

After initial pretesting under these nine conditions, each age group was randomly divided into two training groups. In order to determine whether training effects were specific to the number of distractors present in the field, half of each age group received training under the three full-distractor conditions (i.e., high, medium, and low center task demand with 47 distractors), and half received training under the three half-distractor conditions (high, medium, and low center task demand with 23 distractors). Each observer re-

Table 1. Experimental Conditions for Experiment 1: Pretraining, Posttraining, and Retest Measurements of UFOV

Condition	Center Task[a]	Number of Distractors
1	Present or Absent	0
2	Present or Absent	23
3	Present or Absent	47
4	Smile or Frown	0
5	Smile or Frown	23
6	Smile or Frown	47
7	Same or Different	0
8	Same or Different	23
9	Same or Different	47

[a] Conditions 1–3 are low demand, conditions 4–6 are medium demand, and conditions 7–9 are high demand.

Table 2. Training Conditions

Group	Number of Distractions	Condition[a]	Center Task Demand
1	23	1	Low
		2	Medium
		3	High
2	47	1	Low
		2	Medium
		3	High

[a] Not the same as conditions 1–3 in Table 1.

Table 3. Average Number of Center Task Misses Before and After Training

Center Task Demand	Number of Distractors	Average Number of Center Task Misses					
		Young		Middle Aged		Old	
		Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining
High	47	11.375	5.000	18.625	10.250	18.375	14.500
	23	12.250	3.625	15.250	12.625	19.125	15.000
	0	11.250	4.875	14.000	10.750	22.000	13.000
Medium	47	3.625	0.125	6.000	1.625	8.625	5.250
	23	2.250	0.625	8.125	1.000	8.375	4.625
	0	3.000	1.250	5.250	0.375	7.125	4.250
Low	47	1.250	0.000	2.000	0.125	2.750	1.000
	23	0.375	0.000	0.625	0.375	3.875	0.875
	0	0.625	0.625	0.750	0.250	2.375	0.500

ceived six blocks of trials per practice session, two under each of the three conditions, for five training sessions. After training, each observer was retested under the initial nine conditions to assess the effects of training and the transfer of training from one condition to another. After the posttest measurements, observers were asked to return once per month for a total of 6 months so that the duration of improved performance without further training could be determined.

Results and Discussion

The data are discussed in three separate sections: center task performance, radial localization performance, and permanence of training. Two observers, one in the youngest age group and one in the oldest age group, were deleted from the analysis because of their inability or unwillingness to perform the task under any of the treatment conditions.

Center Task Performance

A 3 (age) × 3 (center task demand) × 3 (number of distractors) × 2 (before and after) analysis of variance (ANOVA) was performed on the number of center task errors. It should be recalled that trials in which the center task was incorrect were recycled into the trial block. We thus had a record of how many trials were recycled within each center task × distractor combination. Table 3 lists the mean number of errors for the nine conditions both pretraining and posttraining as a function of age. As expected, the three center tasks differed in difficulty ($F = 72.09$; df = 2, 38; $p < 0.0001$), with significantly more errors in the high-demand task than in the medium-demand task and significantly more errors in the medium-demand task than in the low-demand task (Tukeys,[37] $p < 0.05$). Furthermore, there was an age difference in terms of the overall number of center task misses ($F = 6.54$; df = 2.19; $p < 0.006$). The older observers made more center task errors than did the young observers, and the middle-aged observers did not differ from either of these extremes (Tukeys, $p < 0.05$). There was neither a (center task condition) × (age) interaction nor a (distractor condition) × (age) interaction in the analysis of center task misses. Even though the older observers missed the center task more frequently (mean misses were 3.45, 6.0, and 8.4 for the young, middle-aged, and older observers, respectively), the pattern of misses was consistent across all center task demands and all distractor conditions.

The pretraining–posttraining analysis showed that center task performance did improve with practice ($F = 41.35$; df = 1, 19; $p < 0.001$); however, this practice effect was present only for the high- and medium-demand conditions and not for the low-demand condition. Performance on the low-demand condition was nearly perfect before practice, and hence there was no room for improvement with practice. These effects are supported by the significant (center task demand) × (practice) interaction ($F = 6.73$; df = 2, 38; $p < 0.003$). This (center task demand) × (practice) interaction was constant across age groups ($F < 1.0$).

Peripheral Localization Performance

Since performance did not vary from one spoke to the next, radial localization errors were summed across the eight radial spokes. Because our data were proportions (percent errors), they were transformed for statistical analysis by taking the inverse sine of the square root of the percent errors.[37] On this scale 1.2 corresponds to chance performance (87.5% errors), 0.79 corresponds to 50% errors, 0.52 corresponds to 25% errors, and 0.0 corresponds to 0% errors.

As shown in Table 2, there were two different training conditions (with either 23 or 47 distractors). Since we did not find a difference between these two conditions ($F < 1.0$), or any interactions involving training condition (all $F < 1.0$ for all comparisons), the subsequent analysis was simplified by collapsing across training conditions.

Thus peripheral localization errors were analyzed in a 3 (age groups) × 3 (center task demand) × 3 (eccentricity) × 3 (number of distractors) × 2 (pretraining versus posttraining) ANOVA, with repeated measurements of all variables except age. Within this analysis, the restriction of the UFOV is demonstrated by a change in performance as a function of eccentricity. Any increased difficulty in localizing the peripheral target as it becomes more eccentric from fixation indicates a reduction in the area from which information can be extracted. The effects of (1) center task demand, (2) distractors, and (3) practice are each described below in terms of their effect on the UFOV (the eccentricity effect) as a function of age. The interaction of these variables with age is presented to illustrate the increased restriction of the UFOV for older adults. Thus the primary focus is on the significant (age) × (eccentricity) × (center task) interaction ($F = 2.92$; df = 8, 76; $p < 0.01$), the (age) × (eccentricity) × (distractor condition) interaction ($F = 5.57$; df = 8, 76; $p < 0.00001$), and the (age) × (eccentricity) × (practice) interaction ($F = 3.30$; df = 4, 38; $p < 0.02$). Since

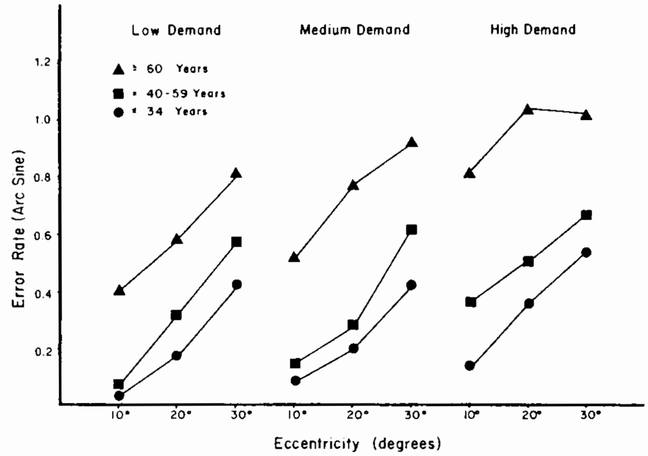

Fig. 2. Radial localization error rates (arc sine transformed) for different center task demands as a function of age and eccentricity.

none of the four- or five-way interactions was significant (all F values were <1.0), the effects of these variables were assumed not to be multiplicative.

Effect of Center Task on Useful Field of View

The effect of center task demand on peripheral localization performance as a function of age and eccentricity is illustrated in Fig. 2. The increase in error rates with increasing eccentricity for all age and center task combinations indicates a restriction of the UFOV. More importantly, the effect of the center task on peripheral performance changes with age. Regardless of the degree of center task difficulty, the difference between young and middle-aged observers is only marginally significant [i.e., for any combination of eccentricity and center task demand the probability that the difference between young and middle-aged observers will be significant (Tukeys, $p < 0.05$) is approximately 50%]. The difference between middle-aged and older observers, however, is significant for every combination of center task demand and eccentricity (Tukeys, $p < 0.05$). Figure 2 shows that the difference between middle-aged and older observers grows with increasing center task demand and increasing eccentricity, thus demonstrating a greater constriction in the UFOV for older observers.

Effect of Distractors on the Useful Field of View

The effect of distractor condition on peripheral localization as a function of age and eccentricity is shown in Fig. 3. As in Fig. 2, there is in general an increase in localization errors as the target is presented farther from fixation. Young and middle-aged observers, again, differ only marginally (i.e., they do not differ in the no-distractor condition, but they differ on 50% of the eccentricities in the two distractor conditions). The older observers, again, make significantly more errors than do the middle-aged and young observers in all distractor and eccentricity combinations (Tukeys, $p < 0.05$). The difference among the three age groups across the three distractor conditions, however, appears stable, other than the relatively error-free performance of the young and middle-aged observers under the no-distractor condition.

Consistent with the training condition results, a comparison of performance under the conditions with 23 and 47 distractors reveals that there were no significant differences between performances under these two conditions for any of the eccentricity and age combinations. The difference between performance with no distractors and that under either of the two distractor conditions is significant for all age and eccentricity combinations except young and middle-aged observers at 10° (perhaps because of a floor effect). Thus, for all observers, the presence of distractors, regardless of number (either 23 or 47) produced a degradation in the size of the UFOV.

The results clearly demonstrate the effects of both center task demand and distractors on the size of the UFOV. The addition of either variable resulted in increased localization errors, particularly at the greatest eccentricities for the oldest observers. The failure to obtain a significant (age) × (eccentricity) × (distractor) × (center task) interaction ($F < 1$; df = 16, 152) indicates that the contributions of these two factors to the restriction of the UFOV are additive.

Effect of Practice on the Useful Field of View

The effect of the third factor that we investigated, practice, is shown in Fig. 4 as a function of age and eccentricity.

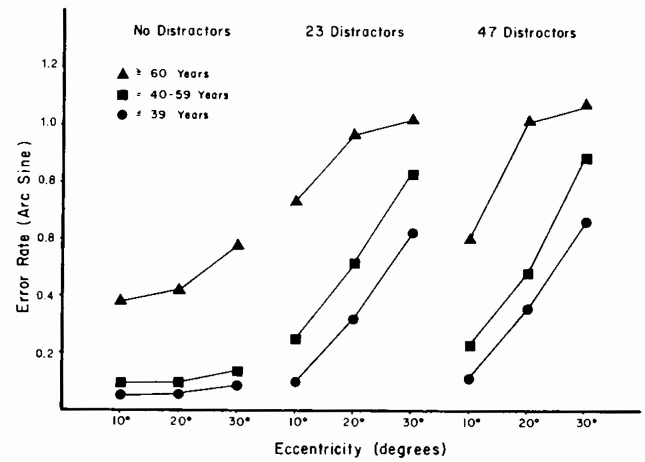

Fig. 3. Radial localization error rates (arc sine transformed) for three different distractor conditions as functions of age and eccentricity.

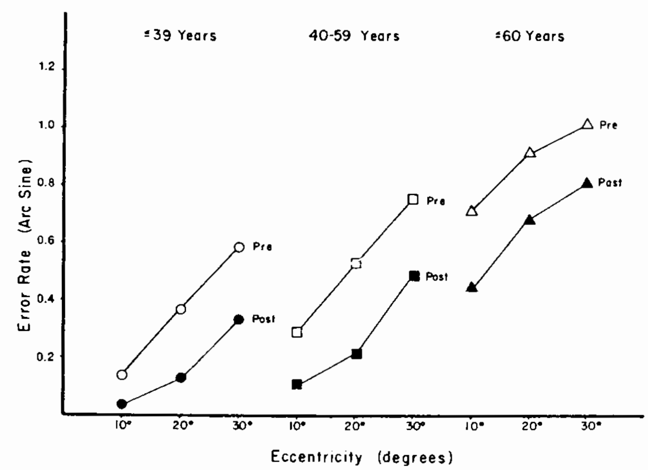

Fig. 4. Radial localization error rates (arc sine transformed) for pretraining and posttraining measures are shown separately for each age group as a function of eccentricity.

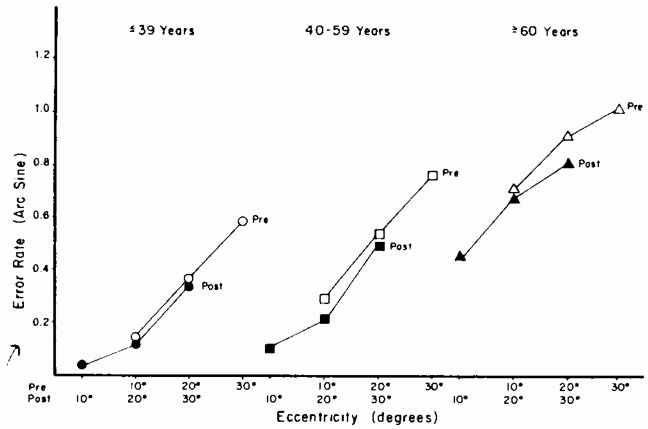

Fig. 5. Data from Fig. 4 replotted with the posttraining eccentricity shifted down 10° relative to the pretraining measures.

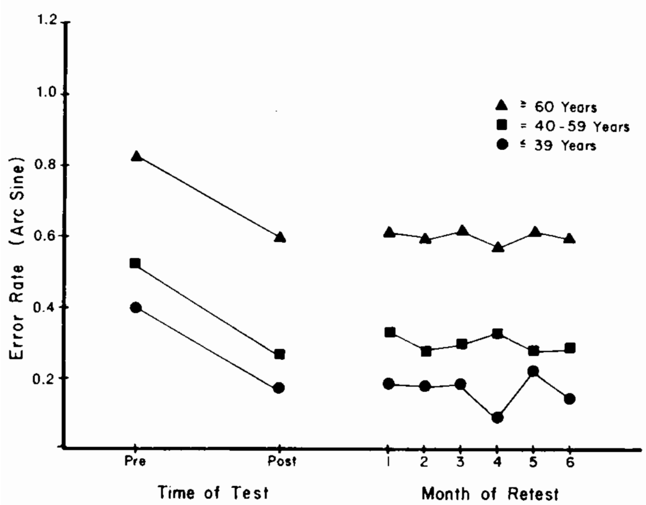

Fig. 6. Radial localization error rates (arc sine transformed) for pretraining, posttraining, and six monthly retests. Data are shown separately for each age group.

Before training, localization becomes increasingly difficult with increasing eccentricity. More importantly, older observers encounter more difficulty than do either young or middle-aged observers (i.e., greater restriction of the UFOV). Pretraining performance of the younger observers at 30° does not differ significantly from that of middle-aged observers at 20° and that of older observers at 10° (Tukeys, $p < 0.05$). The same pattern holds for young observers at 20° and middle-aged observers at 10°. This indicates a 10° loss in UFOV for each increase in age group. Figure 4 also illustrates that practice produced a general improvement in performance at all age and eccentricity combinations except for young observers at 10° (again, there may be a floor effect). Note that the performance of middle-aged observers after practice closely resembles that of young observers before practice. Furthermore, the performance of older observers after practice closely resembles that of middle-aged observers before practice; that is, the 10° loss in UFOV with age appears to be recovered partially with practice.

To demonstrate this recovery in the extent of the UFOV with practice, the data from Fig. 4 are replotted in Fig. 5 with the posttraining data shifted 10° to the left of the pretraining data. Figure 5 shows that the performance of each age group after practice coincides with performance before practice with these shifted axes. Thus it would appear that all three age groups have expanded the UFOV by 10° with practice.

Permanence of Training

Recall that, in order to assess the longevity of improved performance on the localization task, observers were retested on all nine posttraining conditions (three distractor conditions with three center task conditions each) over a period of 6 months at 1-month intervals. Figure 6 illustrates the average error rates, collapsed across distractor conditions, center task conditions, and eccentricity, for all times of testing. A separate ANOVA, performed on only the posttraining data (i.e., posttest and six monthly retests) showed that the improvement in performance after training persisted over this time period ($F < 1.0$). Furthermore, since the time of testing did not interact with any of the other variables, we can conclude that the pattern of results observed in the analysis performed on only the pretraining–posttraining comparison (right-hand side of Fig. 6) does not change over time. Indeed, significant effects in the two analyses match up perfectly (other than the lack-of-practice effects and their interactions in the second analysis).

EXPERIMENT 2

One of the findings of experiment 1 is that reducing the number of distractors from 47 to 23 fails to affect localization performance with this particular target–distractor combination. This is an important point, since other authors noted that the number of distractor elements does have an effect on visual search performance.[27,32] The absence of such an effect suggests a parallel (preattentive) search rather than a serial search on the radial localization task.

Although the results of experiment 1 are consistent with a parallel-processing explanation, it is possible that observers confined their search to the spokes, thus effectively ignoring half of the distractors in the display. Given this strategy, we would not expect to find a difference between the 47- and 23-distractor conditions, since the number of distractors on the spokes was the same for both conditions. Further, if observers were searching the spokes from the fixation box outward, then the eccentricity effect might be accounted for by an increased number of distractors for the 30° condition relative to the 20° condition. For example, no distractors would occur before the target for a 10° stimulus presentation, one distractor would precede the target on the spoke for a 20° stimulus position, and two distractors would precede the target on the spoke for a 30° presentation of the stimulus. In the no-distractor conditions, no distractors would precede the target at any eccentricity, and we would not expect the same kind of eccentricity effect. Practice effects might then be accounted for by an increased speed of serial search, progressing out radially from the fixation box along the eight spokes.

In order to test this possibility, we performed a second experiment in which we varied the placement of distractor elements in the field. By holding the total number of distractors constant and varying the number occurring either on or off the spokes, our goal was to determine whether the density of distractors preceding the target radially or coinciding with a particular eccentricity affected performance on the same radial localization task.

Observers

Six additional young observers were tested on the peripheral localization task (age range, 17–30 years; mean age, 22 years). The average acuity was 0.858-arcmin minimum angle resolvable. All were paid volunteers and were naïve to the purpose of the experiment.

Stimuli

Every trial in experiment 2 consisted of the same four successive computer-controlled displays described for experiment 1. In this experiment there were four distractor conditions. Under one condition the test stimulus appeared without distractors. Under a second condition the face target was accompanied by 23 outline boxes that occupied only potential target positions (only on the spokes). This condition was the same as the 23-distractor condition used in experiment 1. Under a third condition the distractors occupied only the 24 positions between the spokes (none occurred in potential target positions). If observers ignored distractors between the spokes, then this condition would not be expected to differ from the no-distractor condition. Finally, under the fourth condition there were 24 distractors, with 12 presented on the spokes and 12 presented off the spokes. By examining the placement of distractor and target elements, we would then be able to determine whether the number of distractors occupying the same spoke as the target had an effect on performance. The same three center task demands were used in order to make the two experiments comparable.

Procedure

The same procedure was used as in experiment 1. Trials were grouped in sets of 24, and the order of testing of the conditions was randomized for each observer. All observers were tested under all distractor and center task conditions. This combination of task demand and distractor conditions resulted in measures on 12 conditions per observer.

Results and Discussion

Data were treated as described for experiment 1. A 4 (distractor conditions) × 3 (central task demand) × 3 (eccentricities) repeated-measurement ANOVA was performed on the transformed data for the 12 conditions and six observers. Since our primary interest was in the placement of distractors in the field, we first examined the significant effect of distractor condition ($F = 31.12$; df = 3, 21; $p < 0.01$). We found that the three variations in distractor placement and number (23 on the spokes, 24 off the spokes, and 24 mixed on and off) did not differ significantly from one another, but each differed significantly from the no-distractor condition (Tukeys, $p < 0.05$). These results were thus not consistent with the hypothesis that observers were searching only on the spokes (were able effectively to ignore distractors between the spokes) or that the eccentricity effects described earlier could be accounted for by an increased number of distractors for the more-eccentric target presentations. (We should note that we tried reducing the number of distractors even further for four of the observers and found no differences between results for 12 and 24 distractors. At some point there must be a transition between responses for no distractors and for distractors, but it must occur for fewer than 12 distractors for this particular stimulus configuration.)

Age Model of the Useful Field of View

The results reported thus far by ANOVA indicate that the diameter of the area that can be processed in parallel varies with center task demand, distractors, and practice. Furthermore, the interactions of these variables with age (Figs. 2–5), as reported for experiment 1, demonstrate that the effects of these variables on the UFOV are different for each age grouping. In order to model (capture) these effects, we generated separate regression equations within each age group. The models generated from experiment 1 were then validated against data collected in other experiments.

There were several differences between the ANOVA and the regression analyses. First, age was entered within each regression equation as a continuous variable rather than categorically as in the ANOVA. Similarly, eccentricity was also coded as a continuous variable, since the relationship between eccentricity and errors was linear. The independent variables of practice, center task demand, and distractors were coded categorically. Since neither the number nor the placement of distractors produced changes in performance in the two experiments, the vector coding for distractors in the regression analysis compared results for the no-distractor condition with those for any distractor condition (coded as either 0 or 1).

Within each age group, all significant fixed independent variables (i.e., center task demand, distractors, eccentricity, and practice) and the significant interactions between these variables, as determined by ANOVA, were entered simultaneously with age as predictors for radial localization errors.[38] The results of these analyses are shown in Table 4. The R^2 values for the three regression models were 0.61, 0.71, and 0.57 for young, middle-aged and older groups, respectively.

Table 4. Regression Weights for Localization Errors

Variable(s)[a]	Regression Weight for the Following Group[b] Young	Middle Aged	Old
Constant	−0.1272	−0.6966	−0.5679
A	0.0018	0.0133**	0.0088**
D	−0.0726	−0.0289	0.1898**
E	0.0047*	0.0046	0.0087*
H	0.0573	0.2884**	0.3759**
M	0.0169	0.0731	0.0650
P	0.1332**	−0.0489	−0.1467*
$D \times P$	−0.1532**	−0.1327**	−0.0561
$P \times E$	−0.0070**	0.0006	0.0019
$H \times E$	0.0010	−0.0039	−0.0061
$D \times E$	0.0154**	0.0197**	0.0088*
$M \times E$	−0.0003	0.0012	−0.0006
$H \times E \times P$	−0.0019	−0.0050**	0.0035
$M \times E \times P$	−0.004	−0.0043*	−0.0030
$D \times E \times M$	0.0008	0.0003	0.0037
$D \times E \times H$	0.0015	−0.0006	−0.0042

[a] Variables: *A*, age; *D*, distractor; *E*, eccentricity *H*, high demand; *M*, medium demand; *P*, practice.
[b] Significance levels: *, $p < 0.05$; **, $p < 0.01$.

The best fit was obtained for the middle-aged observers because they did not have strong floor or ceiling effects (which occurred for the youngest and oldest groups).

As expected, the pattern of significant predictors differed for the three age groups. Age was a significant predictor within both the middle-aged and older groups but not in the youngest group. This is consistent with greater interobserver variability commonly noted in older age groups and may reflect the cumulative effect of environmental factors on the aging process. Further, the patterns of significant predictors revealed by the regression analyses is consistent with the pattern of effects reported for the ANOVA in experiment 1. For example, Fig. 3, which depicts the (age) × (eccentricity) × (distractor) interaction, shows that within each age group the eccentricity effect becomes much stronger in the presence of distractors. This (distractor) × (eccentricity) interaction is a significant predictor in all three regression models. Center task demand, however, is a significant predictor for only the oldest age group. This is consistent with the results reported in Fig. 2. Similar points could be made about ANOVA results and the other significant predictors revealed by the regression expressions in Table 4. (It should be noted that either a main effect or an interaction could enter into the model prediction as the carrier of an effect, given that these two potential predictors must be correlated themselves.) Since the ultimate goal of the regression analyses presented in Table 4 was the prediction of localization performance in a new sample, we now present such a test.

Test of Regression Model

In order to test the model prediction from the first experiment, we used the regression coefficients obtained with the younger observers in experiment 1 (see Table 4) to calculate predicted localization errors. We then calculated the correlation between the percent errors obtained in experiment 2 with those predicted from experiment 1. The correlation of 0.8124 indicates quite a good agreement between the model prediction and the performance of this new young sample.

We also wished to evaluate the predictive ability of the regression model on an older sample of observers. The study reported by Sekuler and Ball[25] contained data for an older sample of observers with a task similar to the one reported here. In the study of Sekuler and Ball, the older observers were tested on localization accuracy as a function of center task demand, the presence of distractors, training, and eccentricity. Since some of the eccentricities used by Sekuler and Ball were outside the range of eccentricities used to generate the regression model (i.e., 5°), only the data from 10° and 15° eccentricities were used. The correlation of 0.6394 between the predicted errors and the performance of these older observers is quite high, given that we have only comparison data at the closest eccentricites of the model (i.e., 10° and 15°). We would expect a better fit to the data in situations in which the full range of eccentricity is examined.

GENERAL DISCUSSION

To reiterate, the major findings of the experiments described here are (1) that the UFOV varies with age and practice; (2) that the benefits of training are equal for all ages and endure at least up to 6 months; (3) that the regression models that best capture the effects of distractors, eccentricity, center task demand, and practice on peripheral localization performance are different for different age groups; and (4) that these models can successfully predict the extent of the UFOV in a new sample.

As stated above, figural similarity between a target and its embedding context plays a large role in determining whether the target pops out (i.e., can be perceived preattentively) or requires a serial search to determine its presence, location, or identity. In the no-distractor condition, there is extreme dissimilarity between the face target and its background, and thus the target is perceived easily at all eccentricities. In the distractor conditions, although the target still pops out in a preattentive fashion (as indicated by a lack of distractor number effect), the diameter of the area that can be processed is reduced, as indicated by a pronounced eccentricity effect. These results are consistent with the findings of Bergen and Julesz,[31] who reported that the diameter of the area that can be processed in parallel varies as a function of the figural similarity between a target and its background.

In a related study, Plude *et al.*[32] had observers in different age groups perform a visual search task, based on feature-integration theory, to determine whether age decrements in visual search occur in the first stage of feature extraction, where feature detectors operate in parallel, or in the second feature integration stage, which operates serially. In contrast to the findings presented here, they found no age differences in the earlier, parallel-processing stage (i.e., there was neither an eccentricity nor a distractor number effect). The discrepancy in results may be due to differences in figural similarity between target and distractor elements in the two studies. In the study of Plude *et al.*[32] the target and distractor elements differed in two dimensions (color and form), which were selected to yield maximal discriminability. Given such a dissimilarity between target and background stimuli and measures limited to a 10° diameter, age differences may not have surfaced. Given less discriminability between target and distractors and a 30° diameter, as in the present investigation, age differences in the early parallel-processing stage may become more evident.

Another difference between the task presented here and other visual search tasks is the use of a secondary central task. As stated earlier, the older adults make more-frequent errors on the central task, as well as on the peripheral localization task, and errors for all age groups increase with increasing complexity of the central task. One possible effect of the central task could be to consume all the available processing time, leaving little or no time for performing the peripheral localization component of the task. This argument assumes that the central task and the peripheral task are performed serially. Although it is impossible to determine the validity of this assumption from the experiments presented here, we subsequently trained three age groups of observers on the happy-or-sad center task condition to the level of 100% accuracy with a brief presentation duration.[34] After all observers achieved this criterion, we added the peripheral component of the task. Under these conditions we found that older observers could no longer perform either of the tasks (center or peripehral), whereas young and middle-aged observers were able to perform both tasks.[34] This indicates that observers perform the central and peripheral components of the task in parallel. Addition of a central task, thus requiring the simultaneous processing of two targets, is most detrimental to the older individual, and performance on both the center task and the peripheral task declines. Similarly, with practice, performance improves for both the central task and the peripheral localization task. This explanation is consistent with the results of other studies showing decrements with increasing age in the ability to ignore irrelevant detail[39–42] and to perform divided-attention tasks.[43]

Another way of looking at available processing time as a function of age is with respect to the stimulus-persistence hypothesis.[44] This hypothesis postulates that stimuli persist longer in the nervous systems of older individuals and thus would be more susceptible to the presentation of a mask after some brief presentation duration. Results of several studies support the hypothesis that older individuals have a slower speed of perceptual processing.[45–50] Since we used a mask to obliterate any residual afterimages on the display, it is possible that the slower processing of the older individuals did not leave sufficient time to perform the task. We do not believe, however, that older observers were precluded from performing the task at all, since they made far fewer errors for targets presented at 10° eccentricity than for those presented at 30° eccentricity. Rather, the results seem consistent with the hypothesis that the size of the UFOV that can be processed in parallel varies with duration, age, and practice.

There have been mixed results in finding improvement with practice in various types of visual search tasks. Salthouse and Somberg[51] found that age differences persisted across 50 separate sessions for a visual scanning task. Walsh[52] reported that older adults did not improve as much on a visual search task over 18 sessions as did younger or middle-aged observers. It could be that age-related problems in selective attention, which may occur past the parallel stage of processing reported here, are less susceptible to improvement with practice.

The present results are quite clear in demonstrating that the size of the UFOV varies with age. Age differences in visual information processing have at times been attributed to such factors as poor acuity, problems in fixation stability, and eye movements. We do not believe that any of those factors is responsible for the age differences reported here. As was noted in a previous study,[25] varying acuity does not significantly affect radial localization errors for the range of acuities reported in the present study. Indeed, the correlation between localization errors and acuity across all ages in experiment 1 was −0.0154, indicating that acuity plays a minor role in the performance of these tasks. In addition, it was shown that visually healthy older observers achieve fixation stability comparable with that of their younger counterparts for the durations used in this study.[53] Finally, the brief exposure durations used in the present investigation were intended to minimize saccadic eye movements.

Given that the size of the UFOV shrinks with age, how would this be expected to affect everyday performance? Morgan's anecdotal report on how vision changes affected his everyday vision are of interest here. He stated that "I have the impression that my working visual fields, in contrast to my clinically measured fields (which are normal), are somewhat reduced. . . . Objects coming from my right that I missed on casual observation sometimes suddenly appear in my field. I think I have to make a greater effort than before to perceive objects in the periphery of my field. If I give my full attention to detecting peripheral objects, as in visual field testing, my performance is excellent. But when my attention is divided, as in driving, I think that there has been a decrease in the size of my visual fields." [54]

This subjective account is consistent with the findings of several other investigations. For example, Cerella[33] argued that age reduces the size of the perceptual window, thus limiting the quantity of information extracted in a given fixation. Similarly, Scialfa *et al.*[27] proposed a model in which older observers take smaller samples from a given visual scene and must scan each sample more slowly. Our own results are consistent with both of these views and extend them to situations in which observers perform a task preattentively rather than serially. Additionally, these results provide evidence that age-related reductions at this level of processing are susceptible to reversal with practice.

CONCLUSIONS

In conclusion, it appears that the size of the useful visual field is reduced in visually healthy older adults with good acuity. However, this visual field shrinkage can be reversed at least partially by a relatively small amount of practice. Standard perimetric tests of visual field, although they are diagnostic of disease, do not demonstrate the kind of loss in performance that is demonstrated in the experiments described here. It is thus not surprising that older individuals report difficulties in their everyday activities that are not addressed in a standard clinical eye examination.

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