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# Relationship Between Visual Sensitivity and Target Localization in Older Adults

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**Older adults commonly report problems in visual search tasks and experience a higher incidence of mobility problems (e.g. falls and vehicle crashes), which involve visual skills. We examined whether target localization problems in the elderly can be adequately explained by impairments in peripheral visual sensitivity, or whether deficits in higher order visual processing are also contributory. Fifty-nine older adults (59–88 yr) who exhibited varying degress of visual field loss (none to severe) were asked to localize briefly-presented, high-contrast targets (3 × 5 deg) in the central 60 deg (diameter) of the visual field, while simultaneously performing a visual discrimination task at fixation. Visual sensitivity accounted for only 36% of the variance in localization performance across subjects, and this relationship grew weaker (13%) when the target was embedded in distracting stimuli, suggesting that impaired attentional skills also underlie older adults' localization problems. Not surprisingly, older adults with severe visual field loss were also poor at localizing targets. However, about half of those older patients with normal or near-normal visual fields also had severe localization problems. These results indicate that despite having good visual field sensitivity, many older adults have serious difficulty locating objects of interest in the environment. This study illustrates that clinical tests for identifying visual performance problems in the elderly must embody stimulus and task features which better reflect the visual demands of everyday life.**

Aging   Visual search   Peripheral vision   Attention   Useful field of view

## INTRODUCTION

The ability to rapidly locate objects of interest in the environment is a fundamental aspect of seeing. Many visual search and target acquisition models have been proposed (e.g. Hoffman, 1979; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989; Treisman & Sato, 1990; Wolfe, 1993), incorporating parallel and serial processing stages and factors such as set size, target conspicuity, spatial location, and prior knowledge. An interesting question is whether these models are useful heuristics for determining the basis of visual search problems in the elderly. Older adults commonly report problems in locating objects (Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988; Sloane, Ball, Owsley, Bruni, & Roenker, 1992), especially in novel environments and among visual clutter, and experience a higher incidence of mobility problems such as falls (Tinetti, Speechley, & Ginter, 1988) and motor vehicle crashes (National Highway Traffic Safety Administration, 1989). Laboratory studies have indeed indicated that many older adults have deficits in selective and divided attention (Hoyer & Plude, 1982; Plude & Hoyer, 1985), exhibit a slowing in the speed of visual processing (Plude & Doussard-Roosevelt, 1989; Salthouse & Somberg, 1982; Salthouse, 1993), and/or have a constriction in the size of the useful field of view (Sekuler & Ball, 1986; Scialfa, Kline, & Lyman, 1987; Ball, Beard, Roenker, Miller, & Griggs, 1988). Thus it seems reasonable to expect that many older adults will have difficulty with tasks which critically depend on visual search skills. This expectation is supported by recent evidence that older drivers who perform poorly on a visual search task are at increased risk for vehicle crashes (Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Ball, Owsley, Sloane, Roenker, & Bruni, 1993).

Current models of visual search have an obvious limitation when applied to understanding object search and localization problems in the elderly. These models were developed on the basis of data from younger adults and explicitly assume intact visual sensory status, e.g. good acuity, contrast sensitivity, peripheral light sensitivity (Wolfe *et al.*, 1989; Treisman & Sao, 1990). However, eye disease and vision impairment are

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relatively prevalent in older adults (Leibowitz, Krueger, Maunder, Milton, Kini, Kahn, Nickerson, Pool, Colton, Ganely, Loewenstein & Dawber, 1980; Tielsch, Sommer, Will, Katz, & Royall, 1990), and excellent vision cannot be an assumption for individuals in this population. Thus, in studying the mechanisms underlying visual search behavior in the elderly, both visual sensory status and higher order visual processing variables must be considered. Our earlier work suggests that this is a promising approach (Ball, Owsley, & Beard, 1990a). We found that despite having excellent visual field sensitivity, some older adults have severe difficulty localizing targets in a visual search task. This study was limited by its small sample which included only older adults in good eye health with good visual function. The present study goes beyond our earlier work by including a large sample of older adults with a wide range of visual sensory capabilities, not just those in good eye health. In addition, rather than quantifying the visual field in terms of a few global measures, the present study analyzes the relationship between visual sensitivity and localization in specific, localized areas of the field.

As a first step toward addressing this issue, we examined to what extent target localization problems in the elderly can be explained by impairments in peripheral vision. The conventional test of peripheral vision in the clinic is a visual field evaluation where (in the case of automated perimetry) light sensitivity is measured at a multitude of points throughout the visual field. Loss of visual sensitivity in the peripheral field is common in old age (Johnson, Adams, & Lewis, 1989) and is also characteristic of ocular disorders (e.g. cataract, glaucoma) typical of late life (Harrington, 1981). Thus, it is worthwhile to ask whether these visual sensory losses are primarily responsible for older adults' visual search problems, or whether one must also appeal to higher order mechanisms to explain their deficits. In this study, target localization was assessed using the useful field of view task as described by Ball *et al.* (Sekuler & Ball, 1986; Ball *et al.*, 1988; Ball, Roenker, & Bruni, 1990b). This task measures a subject's ability to localize a briefly presented target in peripheral vision while simultaneously performing a visual discrimination task in central vision. We chose this task for several reasons. First, the presence of both a central and a peripheral visual task as well as distracting stimuli, as embodied in the useful field of view test, resembles the visual demands of everyday life. Many routine visual tasks (e.g. mobility, object localization) require that the perceiver make decisions about targets that are fixated while also monitoring targets in peripheral vision which coexist with distracting objects. Second, this paradigm has already proven useful in documenting older adults' difficulties in target localization (Sekuler & Ball, 1986; Ball *et al.*, 1988, 1990a, b). Third, the task has good test–retest reliability, $r = 0.92$ (Ball *et al.*, 1990b). And fourth, this task has real-world validity in that it identifies older adults who have driving problems (Owsley *et al.*, 1991; Ball *et al.*, 1993).

## METHODS

### *Subjects*

The sample consisted of older adults since our focus is on understanding the mechanisms underlying target localization problems in the elderly. Subjects were recruited from the Clinics of the School of Optometry, University of Alabama at Birmingham. The goal was to recruit older individuals who exhibited varying degrees and types of visual sensitivity loss, thus facilitating an examination of how sensitivity is related to localization. Inclusion of subjects with ocular disease was a vehicle by which this goal was achieved. Our intent was not to focus on the effects of ocular disease *per se* on radial localization, but on insuring that a range of peripheral sensitivities were present in the sample. The sample consisted of 59 subjects, aged 59–88 yr (mean age 71 yr), 40 women and 19 men. The sample consisted of 37% African American, and 63% Caucasian. Subjects fell into one of six general diagnostic categories: excellent eye health ($n = 2$), cataract ($n = 20$), age-related maculopathy ($n = 4$), subjects with both cataract and age-related maculopathy ($n = 8$), glaucoma ($n = 12$), and "other" conditions ($n = 13$). This last category included subjects with angioid streaks, diabetic retinopathy, optic nerve degeneration, pthisis bulbi, amblyopia, central retinal vein occlusion, and unexplained acuity loss.

### *Procedure*

The protocol consisted of four types of measurements: acuity in central vision, contrast sensitivity in central vision, visual sensitivity in the central 60 deg (radius) of the visual field, and peripheral target localization in the central 60 deg (radius) of the visual field while performing a task in central vision (i.e. the useful field of view task). Acuity and contrast sensitivity measurement were always performed first, with the order of the two peripheral vision tasks counterbalanced across subjects. Each will be discussed in detail below. The entire procedure was 2–3 hr in duration including rest periods and was completed in one visit to the laboratory. Prior to testing, written informed consent was obtained from all subjects after the nature and purpose of the study were explained.

To assess central vision, letter acuity was measured using the ETDRS chart and was scored using the recommended procedure (Ferris, Kassoff, Bresnick, & Bailey, 1982). Viewing distance was 4 m, and mean luminance of the chart was 100 cd/m$^2$. Subjects wore their best distance correction as determined by a recent eye examination within 6 months of testing. Testing was binocular, since the target localization task was performed binocularly and we were interested in examining the relationship between the two. Letter acuity was expressed as the logarithm of the minimum angle resolvable (logMAR). Contrast sensitivity was measured with the Pelli–Robson chart using the standard scoring procedure (Pelli, Robson, & Wilkins, 1988). Pelli–Robson contrast sensitivity is moderately related to the peak of the spatial contrast sensitivity function (Pelli, Rubin, & Legge, 1986; Rohaly & Owsley, 1993). Viewing distance was 1 m, and mean luminance of the chart was 100 cd/m$^2$. Testing was binocular. Following the standard protocol for the chart, subjects wore a +0.75 D spherical lens over their distance correction in each eye.

Visual sensitivity in the central 60 deg (diameter) of the visual field was assessed using a Humphrey Field Analyzer (HFA) Model 620 (Humphrey Instruments, Inc.). Program 30-2 (which evaluates threshold sensitivity in the central 30 deg) and Program 30/60-2 (which evaluates threshold sensitivity in the 30–60 deg region of the field) were performed on each eye using the full-threshold procedure.* We chose these particular programs because they are by far the most commonly used in both clinic and research. Target size was 0.43 deg of visual angle (HFA target size III), and target duration was 200 msec. Background luminance was 10 cd/m$^2$. Target distance was 30 cm, and testing was monocular. Following standard procedure in the HFA, each subject was optically corrected for the near test distance when tested for targets using HFA Program 30-2. This optical correction was based on the subject's best distance correction.

Our ultimate goal was to compare visual sensitivity in various locations of the field with target localization performance (described below). Since localization was performed binocularly, for purposes of comparison visual sensitivity for a given region of space was expressed in binocular terms. Thus, the Humphrey monocular maps for each eye were combined into a single binocular map. Sensitivity for a given point in space was defined as the sensitivity of the eye having better sensitivity at that location.

Target localization was measured using the standard protocol of the Visual Attention Analyzer, Model 2000 (Visual Resources, Inc.). This instrument measures the size of the useful field of view, operationally defined as the area of visual field over which a person can localize targets presented briefly in the periphery (Ball *et al.*, 1988, 1990b; Ball & Owsley, 1993). This radial localization task is carried out while the peson simultaneously performs a discrimination task in central vision. Several crucial test parameters are varied during testing, such as duration of the target display, the radial location and eccentricity of the peripheral target, and the presence vs absence of distracting stimuli in the periphery. The details of this test are provided below.

The instrument consisted of a 386 computer interfaced with a large video monitor (20 in. diagonal) for displaying test targets. Subjects viewed the display binocularly at a test distance of 23.5 cm. Previous work indicated that optical blur (up to 6 D) resulting from this test distance does not affect performance in this task (Sekuler & Ball, 1986). Thus correction for presbyopia was not added. All test displays were presented at high contrast (99%) and consisted of white targets against a black background. The space average luminance of the target display was 2 cd/m$^2$. The background luminance of the display was 0.03 cd/m$^2$, which is lower than that for the HFA's background (10 cd/m$^2$). However, previous research has indicated that radial localization tasks are not affected by the background luminance level as long as targets are suprathreshold (Leibowitz, Myers, & Grant, 1955).

The first subtest of the useful field of view (UFOV) test measured the stimulus duration required by the subject to identify a target presented in central vision. The target was a silhouette of either a car or truck, and subtended 3 (height) × 5 (width) deg of visual angle. At the beginning of each trial, the subject gazed into a fixation box appearing in the middle of the screen. A target was then briefly presented (from 17 to 332 msec in duration depending on the trial), followed by a spatially random noise mask which destroyed the afterimage. The next screen then asked the subject, "What was in the center box? Car (picture of car) or Truck (picture of truck)". The subject answered the question by touching either the car or truck on the screen, and since the instrument had a touch screen, the subject's response was automatically recorded by the computer. The task began with a stimulus duration of 240 msec. Duration was decreased after two consecutive correct responses to a target of a given duration, and duration was increased after each incorrect response. The step size of the increase or decrease ranged from 17 to 50 msec, depending on how many errors were made in the previous trials. Eight reversals from correct-to-incorrect responding (or vice versa) were recorded, and the threshold duration was defined as the geometric mean of the last five reversals. In this fashion, Subtest One estimated the minimum duration at which the subject could correctly identify the central target 75% of the time, and thus was a measure of the speed of visual processing.

Subtest 2 also required the identification of the central target, as described above. However, simultaneous to the presentation of the central target, a peripheral target (a silhouette of a car 3 × 5 deg of visual angle) was also presented. This target appeared unpredictably at each of 24 different peripheral locations along eight radial spokes (four cardinal and four oblique) at three eccentricities (targets centered at 10, 20, or 30 deg). In order to insure that subjects were attending to the central target, trials in which the center target was incorrectly identified were discarded from further analysis. Trials in which the center target response was incorrect were randomly presented again somewhere within that particular block of trials. This screen was presented for a duration between 40 and 240 msec, in 40 msec increments, depending upon each subject's ability to perform the task. Subtest 2 began with a stimulus duration of 160 msec if the minimum duration determined in Subtest 1 was 40 msec or less. If the minimum duration from Subtest 1 was between 41 and 80 msec, then the

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*The localization targets fell into a central 30 deg (radius) area, and on this basis, one might assume that the test points from HFA Program 30-2, which purportedly measures out to 30 deg (radius) in the visual field, would be sufficient for this comparison. However, the test points of Program 30-2 actually extend to 28 deg, not 30 deg. Thus, a few points from Program 60-2 were used to fill out the field to 30 deg.

beginning stimulus duration in Subtest 2 was 200 msec. If the minimum duration from Subtest 1 was >80 msec then the beginning duration in Subtest 2 was 240 msec. If the subject was unable to perform the task at the beginning stimulus duration for Subtest 2, then the duration was increased in 40 msec steps until it was determined that the subject could not perform the task at the maximum duration of 240 msec. Similarly, if the subject was able to perform at 160 msec, then duration was decreased in 40 msec steps until the minimum stimulus duration at which the subject could perform the task was determined.

On a given trial, after the subject answered the center task question (i.e. what was in the center box?), the next screen displayed an eight-spoke arrangement of lines. The subject indicated along which meridian the peripheral target had appeared by touching the appropriate spoke, which the computer automatically registered since the monitor had a touch screen.

Subtest 3 was very similar to Subtest 2, the sole difference being that in Subtest 3 the peripheral target was embedded in 47 distracting stimuli (triangles subtending 3 × 5 deg of visual angle) distributed throughout the 30 deg field. As in Subtest 2, the subject had to identify the centrally presented target, and to also indicate the radial localization of the peripheral target.

The main purpose of this study was to compare performance in the radial localization task to performance on the visual sensitivity (HFA) task. Before beginning data analysis, a "scaled localization score" was computed for each of the 24 peripheral target positions in the localization task, for each subject. This provided a way of obtaining a single localization-performance measure at each target position, which could then be compared to the visual sensitivity for that visual field region as provided by the HFA task (see Fig. 1 described below). This scaled score was computer separately for Subtest 2 (no distractors) and Subtest 3 (distractors). The scaled localization score was computed as follows. The radial localization task was performed at different durations for different subjects, depending on the capabilities of the subject. Thus, a scoring procedure was developed which gave a subject "credit" for correctly localizing targets at briefer durations than other subject. We devised the following. Recall that the six stimulus durations used in Subtests 2 and 3 were 40, 80, 120, 160, 200, and 240 msec. The scaled localization score was defined as the briefest duration where subjects could localize correctly, plus those briefer durations where he/she could not localize correctly. For example, if a subject localized the target at the briefest duration presented, 40 msec, then that subject was given a scaled localization score of 40. If a subject could correctly localize targets at 80 msec, then that subject received a scaled localization score of 80 plus all durations briefer where they incorrectly localized the target, i.e. 80 + 40. If the briefest duration that a subject could correctly localize targets was 120 msec then the scaled localization score was 120 + 80 + 40, or 240. And so on, if the briefest duration where a subject localized was 240 msec or greater, the subject received the maximum score of 840, i.e. 240 + 200 + 160 + 120 + 80 + 40. There is one additional aspect of the scoring system we need to address. Originally we thought we could simply designate the minimum duration at which a subject correctly localized, as the localization score. Instead the summation procedure described above was chosen so that we could take into consideration those subjects whose performance was not a neat progression from incorrect to correct as duration increased. For example, let us consider Subject A who could localize correctly at 120 msec, not at 80 msec, but could localize at 40 msec. This subject's performance seemed to us superior to Subject B who could localize correctly at 120 msec, but not at 80 msec *and* not at 40 msec. Thus Subject A's scaled localization performance was 120 + 40 = 160, and Subject B's 120 + 80 + 40 = 240. The scaled localization score was strongly correlated ($r = 0.96$) with the standard scoring method in the useful field of view task which expressed performance in terms of a percent reduction in the diameter of the useful field of view (see Ball *et al.*, 1990b).

## RESULTS

The first issue of interest is the relationship between localization performance and visual sensitivity. Percent correct localization was expressed in terms of scaled localization performance (as discussed above), with higher numbers indicating greater localization problems. For each visual field area where a UFOV target was presented, the visual sensitivity for that area of visual field was defined as the average of all HFA points falling within that area or near to it. Figure 1 displays the UFOV target locations and the HFA points from Programs 30-2 and 60-2 used to compute visual sensitivity for those regions of visual field. Depending on the specific target location, four or five HFA test points were used to compute the visual sensitivity for a specific target location. As is the convention in the HFA, sensitivity was expressed in terms of a log scale of sensitivity, i.e. decibels of attenuation of a maximum 10,000 apostilb target. Thus, higher numbers indicate greater sensitivity.

Table 1 lists the correlation coefficients for localization performance and visual sensitivity at each target location, for Subtests 2 and 3 separately. For each eccentricity ring (10, 20, 30 deg), target locations are numbered consecutively starting at 12:00 and moving clockwise. Within each Subtest, there is remarkable similarity in the $r$-values across target locations and eccentricity rings. For Subtest 2, $r$-values average 0.61 (range 0.52–0.71). For Subtest 3, $r$-values are lower, averaging 0.36 (range 0.25–0.44).

Given that the strength of the association between localization performance and visual sensitivity was highly similar across all target locations, we combined all locations within a given eccentricity ring into a single scatterplot, as depicted in Fig. 2. Each eccentricity is graphed separately because it is well known that both localization and sensitivity are eccentricity dependent.

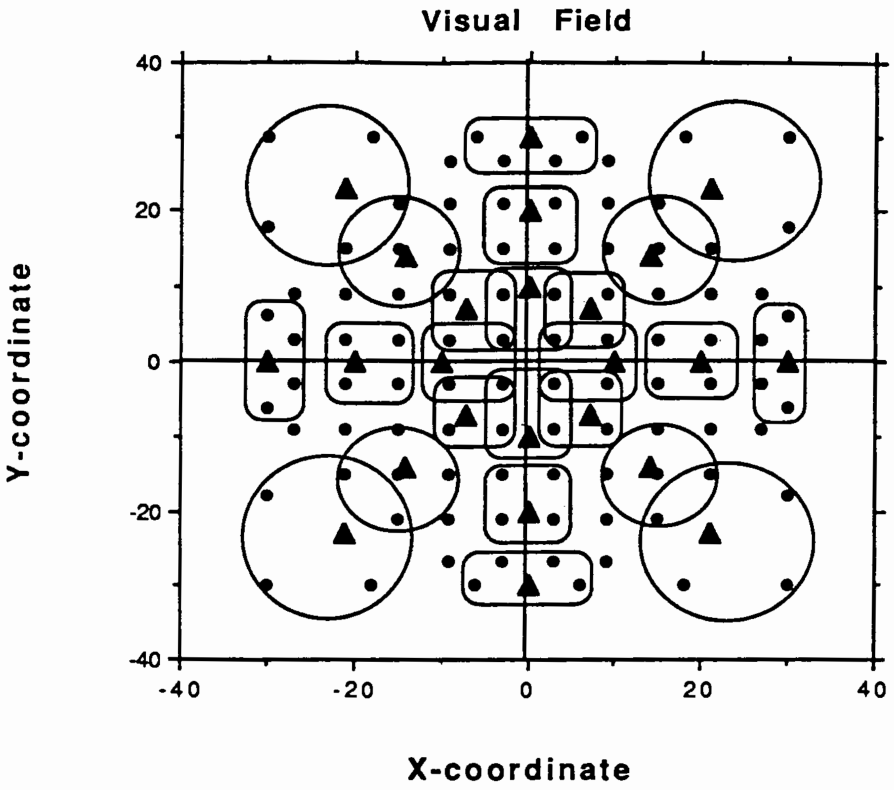

FIGURE 1. Locations in the visual field of the targets from the UFOV task and from the HFA task. The solid triangles mark the positions over which the UFOV targets (subtending 3 × 5 deg) were centered. The solid circles represent the positions of the HFA targets. The curvilinear lines circumscribe the HFA points used to compute visual sensitivity in the region of each UFOV target.

Within a single graph, there are 59 subjects represented. For each subject there are eight targets in an eccentricity ring, all presented on a single graph for that eccentricity ring. Thus, each graph contains 59 × 8 points. Target localization is significantly related to visual sensitivity at each eccentricity, with the results highly similar across eccentricity, Pearson $r = -0.58$ to $-0.61$ (d.f. = 472, $P < 0.001$). For example, visual field locations with poor visual sensitivity were associated with severe localization problems at that field location. However, overall, visual sensitivity accounted for only 36% of the variance in localization, implying that other factor(s) contribute to an older adults' ability to localize a peripheral target. Figure 3 is analogous to Fig. 2, except these are the results from Subtest 3 where the peripheral target is embedded in distracting (non-target) stimuli, which makes the task more challenging. The correlation between visual sensitivity and localization performance once again was significant and highly similar across eccentricity ($r = -0.34$ to $-0.38$, d.f. = 472, $P < 0.001$). Most notably, though, in Subtest 3 where the distractors are present, visual sensitivity accounted for even less

TABLE 1. Pearson correlations between localization and visual sensitivity for each target position in Subtests 2 and 3

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subtest 2* | | | | | | | | | |
| 10 deg | Target position | 1 | 2 | 3 | 4 | 6 | 6 | 7 | 8 |
| | | − 0.58 | − 0.60 | − 0.64 | − 0.61 | − 0.55 | − 0.52 | − 0.56 | − 0.61 |
| 20 deg | Target position | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | − 0.64 | − 0.56 | − 0.60 | − 0.66 | − 0.57 | − 0.62 | − 0.66 | − 0.63 |
| 30 deg | Target position | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | | − 0.54 | − 0.58 | − 0.63 | − 0.63 | − 0.71 | − 0.63 | − 0.60 | − 0.60 |
| *Subtest 3* | | | | | | | | | |
| 10 deg | Target position | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | | − 0.39 | − 0.34 | − 0.39 | − 0.39 | − 0.36 | − 0.33 | − 0.36 | − 0.40 |
| 20 deg | Target position | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | − 0.39 | − 0.28 | − 0.41 | − 0.38 | − 0.38 | − 0.41 | − 0.42 | − 0.41 |
| 30 deg | Target position | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | | − 0.32 | − 0.25 | − 0.39 | − 0.31 | − 0.44 | − 0.35 | − 0.34 | − 0.31 |

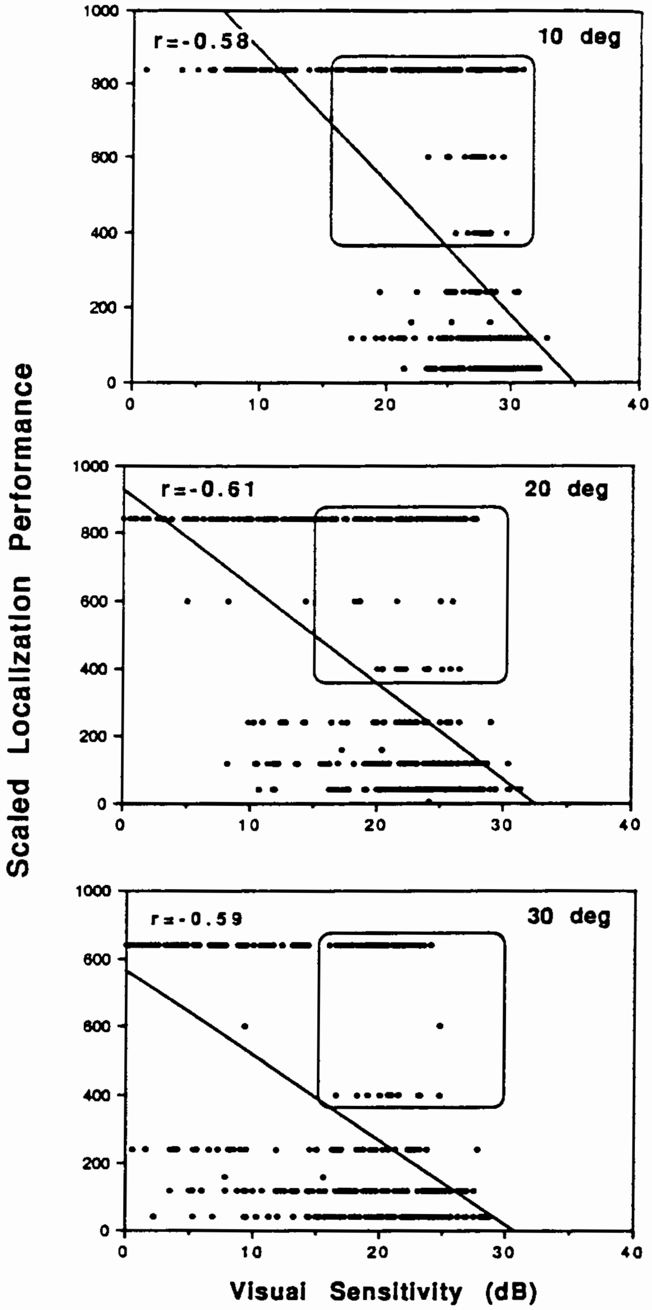

FIGURE 2. Scatter plot showing the relationship between scaled localization performance in Subtest 2 (no distractors) and visual sensitivity, for each eccentricity (as labeled). The demarcated area in the upper right of each panel indicates those subjects whose severe localization problems would not have been detected by conventional visual field testing.

localization variance (13%) than when the distractors were absent (36%).

An interesting aspect of both Figs 2 and 3 is that as visual sensitivity increases, the variability in localization performance dramatically increases (for each panel, $P < 0.01$ using the Cochran Test for homogeneity of variance, see Winer, 1971, p. 208). When visual sensitivity is poor, accurate localization is nearly impossible. As visual sensitivity improves, it is difficult to know what to predict—localization could remain poor, or it could be highly accurate.

The boxed-in areas in each panel of Figs 2 and 3 illustrate those field locations where localization was poor, yet visual field sensitivity was moderately good. (The borders of the boxed-in areas are identical to those cutpoints used in Table 1.) Points in this area illustrate that the serious localization problems experienced by some older adults would have gone undetected by standard visual field testing as conventionally carried out in the clinic. Table 1 quantifies this point. All subjects were divided into those having good vs poor visual sensitivity, and those having good vs poor radial

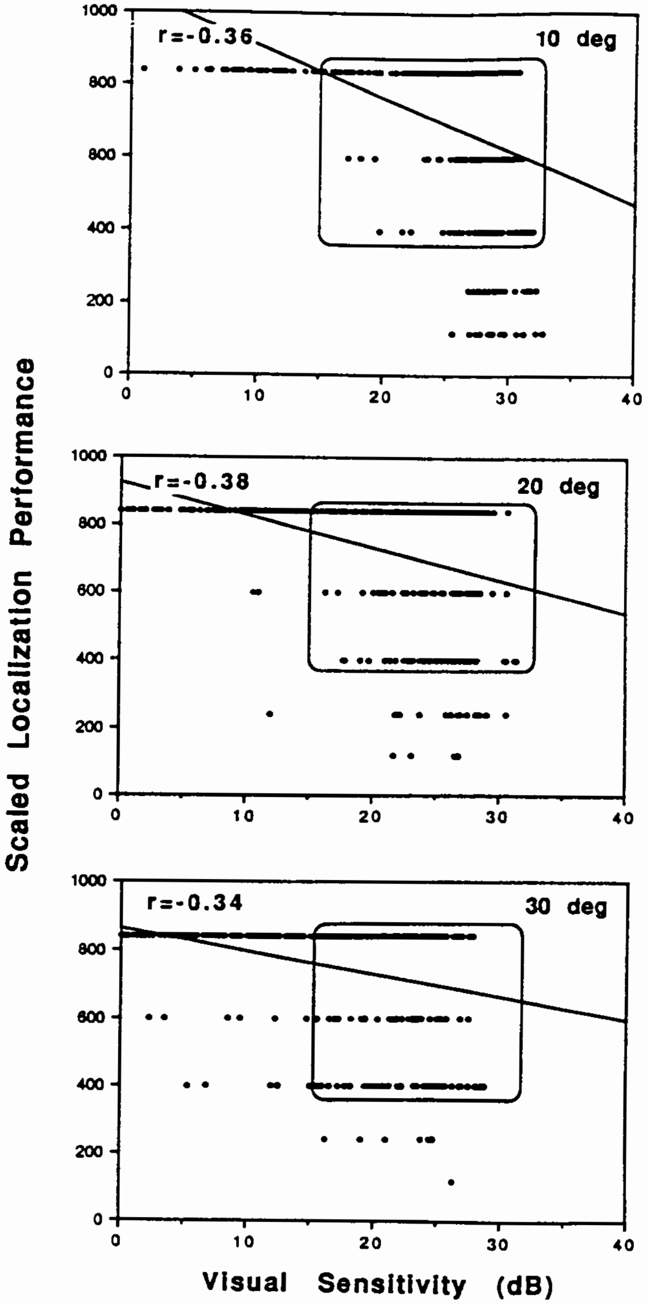

FIGURE 3. Scatter plot showing the relationship between scaled localization performance in Subtest 3 (distractors present) and visual sensitivity, for each eccentricity (as labeled). The demarcated area in the upper right of each panel indicates those subjects whose severe localization problems would not have been detected by conventional visual field testing.

TABLE 2. Number of subjects with good vs poor performance in each task

| | Visual field sensitivity | |
|---|---|---|
| Localization performance | Poor sensitivity | Good sensitivity |
| Poor localization | 16 | 20 |
| Good localization | 1 | 22 |

localization performance in Subtest 2 of the UFOV task. For the purposes of categorization, "good" visual sensitivity was defined as average central 60 deg field sensitivity of 15 dB or greater, and "poor sensitivity" less than 15 dB. "Good" radial localization performance was defined as a scaled radial localization performance less than 400, and "poor" localization as 400 or greater.* The number of subjects falling into each category is listed in Table 1. Almost all (90%) subjects having poor visual sensitivity also had poor localization performance. This is the same point that was obvious from the scatter plots in Figs 2 and 3. However, subjects having good visual field sensitivity were split about evenly between poor vs good localization. 48% of subjects with good visual field sensitivity had poor localization performance, and 52% had good localization performance.

A small but noticeable number of subjects had good localization performance at 30 deg eccentricity despite their having poor visual sensitivity in the visual field area where the target was presented (see Fig. 2, bottom panel). This is also true at 20 deg eccentricity, although to a lesser extent. One possible explanation for this phenomenon is that since visual field sensitivity was assessed at only a small number of punctate points (four or five) in the region of the target area, it is conceivable that there was enough residual vision in the areas not assessed by the HFA, to permit detection of the peripheral target in the UFOV task. Another potential explanation stems from the fact that spatial summation increases with increasing eccentricity. It could be the case that by 30 deg in the periphery, spatial summation has increased enough so that detection and localization of the target is made possible even in those areas having poor light sensitivity. This phenomenon is only weakly present in Subtest 3 where there were distracting stimuli (see Fig. 3, 30 deg bottom panel). The distractors made the task more difficult in that subjects in general required longer duration displays to successfully localize the target, and thus their scaled localization scores are displaced to higher positions on the y-axis.

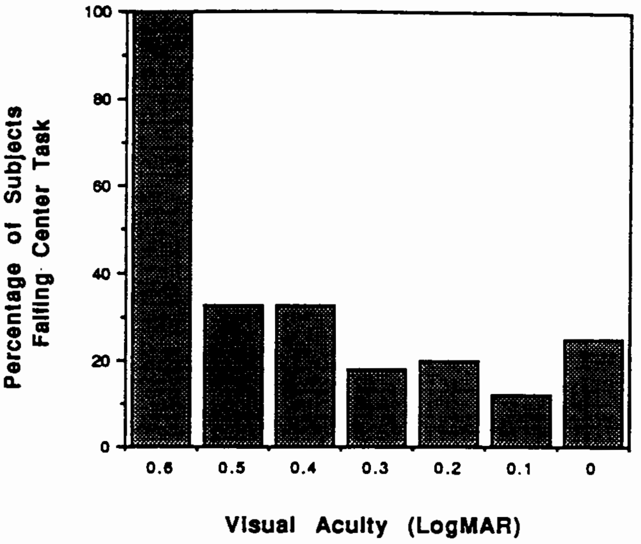

FIGURE 4. Percentage of subjects in each acuity category who failed the center task.

Subjects were also required to make a visual discrimination in central vision, while localizing the peripheral target. Mean visual acuity for our sample was 0.15 logMAR, range −0.12 to 0.54 logMAR, and mean log contrast sensitivity was 1.65, range 0.60–2.10. We wondered to what extent impairments in central vision in older adults would affect central task performance in this type of "divided attention" task. That is, what levels of acuity and contrast sensitivity in central vision are required to perform a "center task" while simultaneously performing a peripheral localization task? Figure 4 portrays the percentage of subjects in each acuity category who failed the center task. Failure in the center task is defined by inability to identify the car vs truck at the longest test duration (240 msec) in Subtest 2. All subjects having logMAR acuity worse than 0.5 failed the center task, as opposed to a rate of only 20–25% failures in those with 0.5 logMAR acuity or better. With respect to contrast sensitivity, Fig. 5 shows

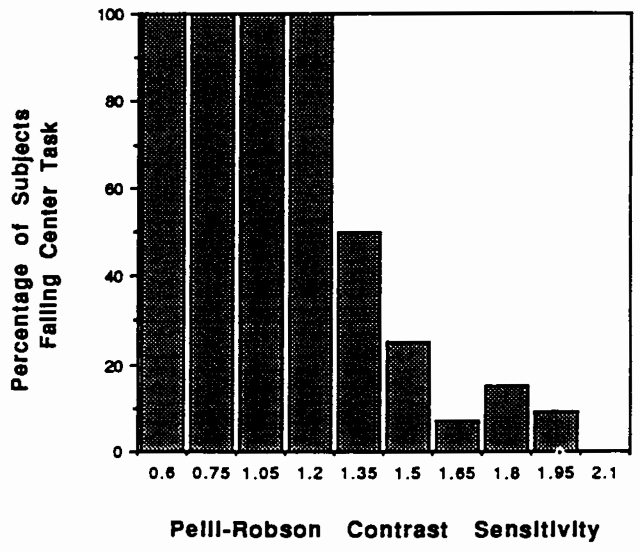

FIGURE 5. Percentage of subjects in each contrast sensitivity category who failed the center task.

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*The cutpoints for visual sensitivity and localization in Table 1 were determined as follows. Figure 2 suggested that in most cases, visual field regions with visual sensitivity below 15 dB could not support localization, i.e. there is a distinct lack of points in the lower left portion of each graph in Fig. 2, beginning around 15 dB. With respect to the localization variable, a scaled score of 400 or greater approximates a useful field of view reduction of 40% or greater, which we earlier found places older drivers at risk for crashes (Ball *et al.*, 1993).

that all subjects having log contrast sensitivity worse than 1.35 failed the center task, as opposed to a rate of only 10–50% failures in those with 1.35 log contrast sensitivity or better.

Since acuity and contrast sensitivity are common and quick clinical assessments, one might ask whether they are good predictors of localization problems in the elderly. Acuity was not significantly correlated with scaled localization score in Subtest 2 [$r$ (59) = 0.16, $P > 0.05$] or Subtest 3 [$r$ (59) = 0.06, $P > 0.05$]. Contrast sensitivity, however, was significantly related to localization in both Subtest 2 [$r$ (59) = 0.44, $P < 0.01$] and Subtest 3 [$r$ (59) = 0.20, $P < 0.05$]. Both acuity and contrast sensitivity are measures of central vision, and thus it is not very surprising that these measures are not linked or only weakly linked to a peripheral localization task. Average visual field sensitivity was more strongly related to scaled localization (Subtest 2, $r = 0.68$, $P < 0.01$; Subtest 3, $r = 0.48$, $P < 0.01$) than were these measures of central vision, again not surprising given that the localization task and the HFA task utilize peripheral vision.

## DISCUSSION

These results imply that despite having moderate to excellent visual field sensitivity, and good acuity and contrast sensitivity in central vision, many older adults have difficulty locating objects of interest in the environment. When an older adult presents in the clinic with complaints about seeing or finding objects in the periphery and/or difficulties with tasks which critically depend on peripheral vision (e.g. mobility), the conventional approach includes an assessment of visual field sensitivity, usually with an automated perimeter or one of the commonly used kinetic methods. Our data suggest that this approach by itself is insufficient for identifying older adults with visual search and target localization problems in that many patients with this type of problem will reveal normal or near-normal visual fields. This finding is consistent with the results of an earlier, small-scale study (Ball *et al.*, 1990a). Conventional visual field assessment does indeed correctly predict that older adults with poor visual sensitivity will have serious problems locating objects; if an object is not adequately registered by the visual system, it cannot be attended to. However, conventional field assessment fails to identify that despite having good visual field sensitivity, some patients have localization problems. This shortcoming is not unexpected since perimetry techniques were developed to assist in the diagnosis and monitoring of ophthalmic diseases, and not to predict performance problems in everyday tasks.

An interesting aspect of our data is that the correlation between visual sensitivity and localization performance grew weaker when distracting (non-target) stimuli were added to the display. This illustrates that older adults' problems in activities involving visual search not only stem from visual sensory impairments, but also from attentional deficits. Most routine visual activities involve dividing attention and selectively attending to an object of interest embedded in visual clutter. Thus, a test of visual search skills may be a more comprehensive method for assessing older adults' problems in complex visual activities, since visual search depends not only on visual sensory function, but also on higher-order skills such as attention. Our recent work on driving is consistent with the idea that visual tests which challenge attentional skills may be better at predicting older adults' problems on everyday visual activities than purely visual sensory tests (Owsley *et al.*, 1991; Ball *et al.*, 1993).

A factor which may have contributed to impaired localization in some older subjects is difficulty in maintaining the narrow vergence angle (26 $\Delta$D) at the close testing distance. Older adults are typically presbyopic and thus accommodative vergence would have had a minimal role in maintaining the appropriate vergence demand in this task. One might argue, then, that under these circumstances, considerable fusional vergence would have to be invested to maintain single vision, which may have been difficult for elderly subjects, and especially challenging for brief target presentations as used in this study. The present data cannot determine the impact of this factor on the subjects in the present study. However, we have preliminary evidence that a useful-field-of-view test apparatus which forces older adults to focus at optical infinity yields results highly similar to the conventional apparatus using the near test distance.

This was not an epidemiological study on the prevalence of target localization problems, so in fact we do not precisely know what percentage of the older adult population would pass a visual field assessment yet fail a target localization test. Our subjects were recruited from an eye clinic and chosen because they had a range of eye health problems fairly typical of the older adult population (Tielsch *et al.*, 1990). We did not have prior knowledge about their target localization problems or their visual field sensitivity. Under these circumstances, it is striking that about half the subjects having at least moderately good visual field sensitivity had serious difficulty localizing targets.

Although our study indicates that impaired visual field sensitivity in older adults impedes their visual search abilities, this study also makes clear that for many older adults, impairment of higher order visual processing is the major cause of their visual search problems. The literature has widely documented visual search problems in the elderly, but still there is little consensus about the higher order mechanisms underlying these deficits. Many different views, some contradictory, garner support from the literature. For example, some studies report that the elderly have problems with serial but not parallel search (Plude & Doussard-Roosevelt, 1989), while other studies offer compelling evidence of parallel processing deficits (Sekuler & Ball, 1986; Ball *et al.*, 1988). Most agree that there is a slowing in the speed of visual processing in later life (Salthouse & Somberg, 1982; Salthouse, 1993), although it is unclear whether this slowing is limited to cognitive operations (e.g. working memory), or also extends to early vision (pre-attentive processes). Several studies have found that the size of the attentional window is constricted in older adults (Sekuler & Ball, 1986; Scialfa *et al*., 1987; Ball *et al*., 1988), while others argue that this effect is mediated by reduced acuity in older adults' peripheral field (Cerella, 1985). Recently several investigators have developed models of human search behavior (Treisman & Sato, 1990; Wolfe, 1993) which account for much of the visual search data extant in the field. With regard to our interest in vision problems in the elderly, visual search models allow one to generate specific, testable hypotheses about which visual processing mechanisms remain unimpaired vs break down in later life, making these models useful heuristics for identifying the basis of object search and localization problems in the elderly.

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