Clin. Vision Sci. Vol. 5, No. 2, pp. 113–125, 1990
Printed in Great Britain.
0887-6169/90 $3.00 + 0.00

CLINICAL VISUAL PERIMETRY UNDERESTIMATES PERIPHERAL FIELD PROBLEMS IN OLDER ADULTS

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(*Received* 5 *July* 1988; *in revised form* 16 *May* 1989)

Summary—1. Older individuals frequently report difficulty in everyday activities requiring the use of peripheral vision. However, standard perimetry measurements commonly reveal only a minor age-associated loss in the visual field.

2. The relationship between older patients' reported problems in these everyday activities and visual field measurements was addressed by testing both young and older observers on three tasks: Goldmann perimetry, Octopus automated perimetry and performance on a task to assess the "functional" or "useful" field of view. This task consisted of visual localization of a target under conditions designed to simulate the types of situations older individuals describe as difficult.

3. Each patient's age and performance on all three tasks were entered into a hierarchical regression analysis as potential predictors for the frequency of reported difficulties on visual tasks relating to visual search, mobility, and speed of visual processing (as assessed by survey questions). Only performance on the visual localization task proved to be a significant predictor for survey responses related to these activities. Performance on the localization task showed specificity as a predictor in that it did not predict other age-related difficulties such as light sensitivity and susceptibility to glare.

4. Thus standard perimetric techniques underestimate the severity of many older adults' functional loss in the visual field. While older adults typically show some sensitivity losses throughout the field, assessments of functional vision with our task reveal a dramatic (3-fold) reduction in the visual field for many older individuals relative to their younger counterparts. Assessments of the useful field of view, along with standard clinical evaluation, may help to delineate the visual functions necessary for the performance of routine activities dependent on peripheral vision, such as driving.

Key words—Aging; Goldmann perimetry; Octopus perimetry; static perimetry; useful field of view; visual field; visual search.

INTRODUCTION

When an older patient presents in clinic complaining of difficulty with activities such as visual search, driving, mobility or objects suddenly appearing in the field of view, the routine ophthalmic examination is supplemented by standard perimetry to evaluate the integrity of the visual fields. Frequently, however, not only does the standard clinical examination indicate that the patient has good eye health, but the perimetric examination reveals only a minor age-associated loss in the visual field. This apparent mismatch between clinical data and the patient's report is most likely due to the fact that clinical devices such as perimeters were not originally intended to assess functional vision. The purpose of this study was to systematically examine the relationship between the degree of difficulty both young and older adults experience in everyday visual activities, standard perimetric evaluations and performance on a visual localization task specifically designed to simulate the types of situations older individuals describe as difficult. With an increasing number of older adults continuing to work, drive and participate in an active lifestyle, one long range goal is to identify how visual field assessment can be improved or supplemented to better address older adults' functional vision problems in everyday activities.

It is not well established that sensitivity throughout the visual field is adversely affected by the aging process. Studies using kinetic perimetry have indicated that the borders, or isopters, of the visual field are constricted in older adults (Drance *et al.*, 1967; Wolf, 1967; Burg, 1968; Williams, 1983). In addition, a number of recent studies using automated perimetry have found that older adults exhibit a generalized loss in sensitivity throughout the field, with some studies suggesting a slightly greater sensitivity reduction in more peripheral areas (Haas *et al.*, 1986; Jaffe *et al.*, 1986; Brenton and Phelps, 1986; Johnson *et al.*, 1989).

Johnson *et al.* have reported that age-related changes in the optics of the eye, such as increased lens density and miosis, are not responsible for this sensitivity loss, at least at photopic light levels, implying a neural basis for these visual field changes.

In comparison to these clinical visual fields, the "functional" or "useful" field of view (UFOV) has been defined as the spatial area or visual field extent that is needed for a specific visual task (Sanders, 1970). In contrast to the traditional field it is usually measured binocularly, involves detection, localization, and/or identification of suprathreshold targets, and both the target and background are usually complex. The limits of this field have been found to vary substantially across individuals and situations (Verriest *et al.*, 1983, 1985). For example, the size of the UFOV is reduced when a secondary central task is added (Leibowitz and Appelle, 1969; Ikeda and Takeuchi, 1975; Williams, 1982; Williams and Lefton, 1981; Sekuler and Ball, 1986; Ball *et al.*, 1988), when the target is embedded in background distractor stimuli (Drury and Clement, 1978; Sekuler and Ball, 1986; Scialfa *et al.*, 1987; Ball *et al.*, 1988), and as the similarity between the target and distractor stimuli is increased (Bloomfield, 1972; Engle, 1971, 1974, 1977; Triesman and Gelade, 1980; Julesz, 1981; Bergen and Julesz, 1983; Julesz and Bergen, 1983). Most importantly, for the purposes of assessing the UFOV as a function of age, the impact of these variables is much greater for older individuals (Rabbitt, 1965; Plude and Hoyer, 1985, 1986; Sekuler and Ball, 1986; Scialfa *et al.*, 1987; Ball *et al.*, 1988). These studies have indicated that aging is associated with a deficit in both serial and parallel visual search, as well as a restricted field of view, and that the degree of the restriction can be up to three times greater for visually-healthy older adults than for young adults (Ball *et al.*, 1988). Thus although age-associated decrements occur for both the clinical and functional visual field assessments, age-related declines tend to be much larger for the functional assessment.

Since we were interested in determining how clinical measures of visual field, as well as functional measures corresponded to the daily visual experiences of older adults, we needed some measure of their visual problems in daily life. Very few studies have examined the extent of visual problems experienced by older adults in the real world. Morgan (1988) has reported an apparent age-related constriction of the UFOV in the absence of clinical visual field loss. Additionally, Kosnik *et al.* (1988) asked visually-healthy adults (aged 18–100) to complete a survey which posed questions about the frequency and severity of everyday visual problems. Of particular interest to us was the finding that one cluster of questions (revealed by factor analysis) which related to difficulties in driving, mobility, visual search and a slowing of visual abilities, generated different responses in younger vs older adults. We thus chose to use our own participants' answers to these same questions as an index of their degree of difficulty in these types of activities. We could then determine how well traditional measurements of static perimetry, as well as measurements of the useful field of view, would predict subjects' responses to the survey questions.

METHODS

Subjects

Two groups of observers were tested; 9 younger adults, mean age 21, age range 18–25; and 8 older adults, mean age 70 years, age range 64–77. Written informed consent was obtained from each participant after the nature and purpose of the study were explained. Younger adults were in good ocular health as indicated by their most recent eye health examination. Mean letter acuity for each eye was 20/20 or better as assessed by the Bailey–Lovie chart (both near and far tests).

All older adults were living independently in the community 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. Mean letter acuity for each eye was 20/25 or better, and intraocular pressure was within normal limits (< 20 mm, Hg). Pupil sizes ranged from 2 to 3 mm for the older group and 3 to 4 mm for the younger group at the light levels used in the study. All older adults were determined to be in good eye health, although they did exhibit the increased lens density typical of later adulthood. The important point is that these individuals did not reveal any frank pathological signs by standard clinical evaluation.

Subjects participated in all three tasks described below. In addition, subjects initially completed a survey designed to assess the fre-

Table 1. Survey questions from Kosnik *et al.* (1988)

Item	Questions relating to visual search and speed of processing
6	Have you noticed difficulty going down steps?
17	Have you noticed difficulty reading a street sign when there are many other signs around?
24	Have you experienced lack of confidence in doing things that depend on your vision (such as walking in the dark, going down stairs, driving, etc.)?
29	Do you have to read more slowly than you did in the past?
30	Do you have to stare longer at things to recognize them than you did in the past?
31	Do you have to take more time now than you did in the past and be more careful doing things that depend on your vision such as driving, walking down stairs, etc.)?
37	Is it more difficult for you to participate in any of your hobbies or pastimes because of visual difficulties?

Item	Questions relating to light sensitivity
10	Have you noticed difficulty sorting dark colors (as with black or navy blue socks?)
11	Have you noticed difficulty recognizing faces at a distance?
17	Have you noticed difficulty reading a street sign when there are many other signs around?
18	Have you noticed difficulty recognizing a friend when he/she is standing in a crowd of people?
28	Have you experienced trouble seeing something when lights off to the side are shining in your eyes?
35	Now we would like you to imagine a time when you were trying to look at something (for example a street sign) that you are having trouble seeing because it is directly in the sun. Do you ever have the same or similar difficulty when you are looking at an object and there is a light nearby?

quency and severity of their visual problems in everyday life (see Kosnik *et al.*, 1988, Survey I). The questions relating to mobility, visual search, and visual processing speed (hereafter referred to as Factor 1) are listed in Table 1. It should be noted that reasons for reported difficulty in response to any particular question could be numerous, but that an underlying problem with functional vision could result in reported difficulty to all the questions since these questions relate to variables important in characterizing the size of the useful field of view (Sanders, 1970; Scialfa *et al.*, 1987; Sekuler and Ball, 1986; Ball *et al.*, 1988). It should also be noted that although older adults, in general, report a greater degree of difficulty on these items than do younger adults, many older adults do not report any problems. This diversity among the older age group provides an opportunity to determine whether or not poorer performance on the functional vision tasks is associated with a higher incidence of reported problems within this age group. An additional set of questions, whose responses were also found to differ significantly as a function of age, relates to glare, light sensitivity, and miosis. These questions are also presented in Table 1 and will be referred to as Factor 2. Responses to these questions were used as a control measure to determine whether our visual field assessments would predict difficulties specifically relating to the useful field of view, or would merely reflect an age-related increase in reported visual problems.

In order to calculate comparable overall measures of perceived difficulty for both the seven questions comprising Factor 1, and for the six questions comprising Factor 2, the following procedure was used. First, a total score was obtained for each individual on each factor by adding the response values for each question within that factor (i.e. 0 = never have difficulty, 1 = rarely have difficulty, 2 = occasionally have difficulty and 3 = frequently have difficulty). Since total scores on the two measures were based on a different number of questions (seven for Factor 1, and six for Factor 2), we made the total scores comparable by taking the average score on each factor for each observer and multiplying it by 6.5. Thus the total range on each factor was 0–19.5. As expected, the older respondents reported more difficulty than the younger respondents to both groups of questions, and the average scores (collapsed across age) for the two groups of questions did not differ significantly ($t < 1.0$). Similarly, although there was more variability in the responses of the older respondents, the variability of responses for the two groups of questions was quite similar.

Static perimetry

The central 30 deg of the visual field of the right eye of each participant was assessed using two standard techniques. First, we chose a traditional mode of static perimetry using the Goldmann perimeter to assess the 0–180 deg meridian at fixation and at 5, 10, 20 and 30 deg in both the nasal and temporal fields. Mean luminance of the sphere was 10 cd/m^2 (31.5 asb). Thresholds were measured for a size III target (25.9 min arc diameter) which was presented for 75 ms. Before thresholds were measured, observers were first given a suprathreshold presentation of the target so they "knew" what to expect. Threshold was then approached from below with a step size of 0.1 log units. Threshold for a given visual field location was measured twice. If the threshold was the same, the experimenter moved on to the next test location; if threshold was different a third measurement was made, and the three were averaged. A third measurement was made approximately 50% of the time for each subject.

The second standard technique used to assess the visual field was Octopus automated perimetry. Thresholds were assessed in the central 30 deg by Program 32 which measures threshold at 76 locations in this region of the field. Targets were presented for 200 ms. The luminance of the sphere was the same as in the Goldmann task, 10 cd/m^2. Because older adults were presbyopic, they were given their best optical correction for the near test distance in both perimetry tests.

The useful field of view (UFOV)

Stimuli. Our task, similar to one described earlier (Sekuler and Ball, 1986; Ball *et al.*, 1988), consisted of both a peripheral and central component. The peripheral component was designed to measure how well a target presented in the near-peripheral field could be localized. Localization was assessed both when the target was embedded in distracting stimuli and when it appeared alone. The central component was designed to create varying levels of focal demand and to assess how this demand affected peripheral localization. In the condition in which neither of these task demands (central task nor distractors) were present, our task in some respects resembled clinical perimetry in that there was no demand on central vision, other than to fixate, and no distracting or contextual stimuli in the periphery. With a center task as well as distractors, the task more closely resembled those encountered in everyday situations.

A schematic diagram of the stimulus is shown in Fig. 1. The peripheral target was a cartoon-likeness of a smiling face, subtending 1.5 × 3 deg. The luminance of this target was 2 cd/m^2; the background luminance was 0.03 cd/m^2.

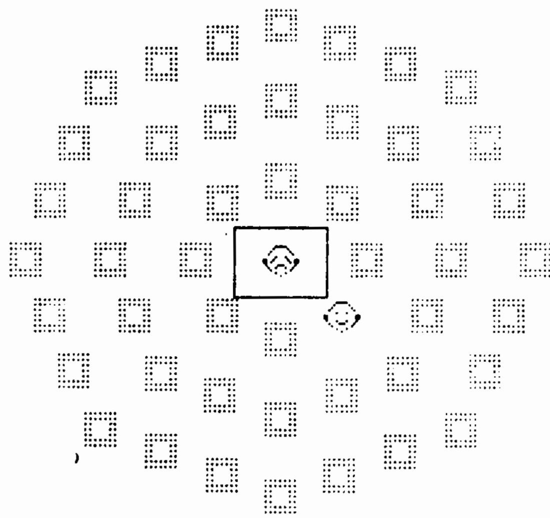

Fig. 1. A schematic representation of the stimulus used in the UFOV task. Portrayed is a frowning face in the fixation box and a peripheral target five degrees from fixation in the presence of background distractor elements.

This target appeared unpredictably, but equally often, in each of 24 different peripheral locations along eight radial spokes (four cardinal and four oblique) at three eccentricities (5, 10 and 15 deg). Distractor stimuli, when presented, consisted of 47 outline boxes of the same size and luminance as the target face. These boxes were distributed uniformly over the central 15 deg of the display and occupied all possible remaining face positions as well as intermediate positions. This particular stimulus was chosen for comparability with our past research, and because it is relatively easy to explain the task to observers. We have found that other combinations of target and distractor stimuli (e.g. X embedded in O distractors), in which the target is equally conspicuous against its background, provide equivalent results.

A central task was used to ensure that observers were fixating the center of the screen, and to determine how performance on the peripheral localization task is affected with concurrent use of foveal vision. Three levels of central task demand were used. In the least demanding condition, observers simply fixated a smiling cartoon face presented in the center of the fixation box but no central target response was required. In a second condition, observers were required to judge whether the face within the fixation box was smiling or frowning (the two expressions appeared equally often in a random order). In the third condition, which was the most demanding, two faces were presented in the fixation box. Half of the time they had the same expression and half of the time they were different. Observers were required to make a same/different judgment.

Every trial consisted of four successive computer-controlled displays presented on a large video screen (CONRAC), 40 × 40 deg at a viewing distance of 57 cm. The first display, a bright outline box (4 × 4.5 deg) with a central fixation point, directed the observer's fixation. One second later the test stimulus, consisting of both the central and peripheral components, was presented for a short duration (either 75 or 125 ms depending upon the condition). These brief presentations prevented saccadic eye movements during the test. Immediately following this second display, spatially random masking noise was presented for one second to obliterate any residual afterimages on the screen. Finally, a radial pattern appeared with eight equally spaced spokes, each labeled with a digit from one to eight. The spoke pattern remained on the screen until the observer indicated the location of the peripheral target.

Procedure. Observers were seated with their heads positioned in a chin rest. For comparability with everyday conditions, binocular viewing was used in testing. Observers wore their best optical correction for the display distance. A keypad, consisting of two labeled buttons at the top 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.

All observers were tested in eight conditions, as outlined in Table 2. The order of testing was randomly determined for each observer. In four of the conditions no center task was required, other than to fixate, and observers responded only to the location of the peripheral target. In two of these four conditions (1 and 3) observers were tested with a stimulus duration of 75 ms for comparability with the Goldmann task. In the other two conditions (2 and 4) observers were tested with a stimulus duration of 125 ms for comparability with the tasks incorporating a central task. Previous work had indicated that a duration of 125 ms precluded perfect performance in all young observers and provided a range of performance abilities in older observers when both a central task and distractors were incorporated into the task. In these conditions, observers responded first to the central task (either the happy/sad discrimination or the same/different discrimination) and secondly to the location of the peripheral target. Each of these two conditions were tested both with and without distractors. If the response to the central task was incorrect the trial was not counted and was re-presented some time later in the block of trials. This was done to assure that observers were in fact attending to the center of the screen.

Table 2. Eight conditions examined to assess the UFOV

	UFOV conditions		
Condition	Center task	Distractors	Duration
1	Fixate	None	75 ms
2	Fixate	None	125 ms
3	Fixate	Yes	75 ms
4	Fixate	Yes	125 ms
5	Happy/sad	None	125 ms
6	Happy/sad	Yes	125 ms
7	Same/diff	None	125 ms
8	Same/diff	Yes	125 ms

Trials were blocked in sets of 24. This allowed one presentation of the peripheral target at each of its 24 possible positions. The number of actual trials varied slightly depending on the number of center task misses, but this represented a small fraction for each observer. On the happy/sad discrimination young observers erred 6% of the time, and older observers erred 7.9% of the time. On the same/different discrimination younger observers erred 8.9% of the time and older observers erred 10% of the time. Neither of these differences were statistically significant ($t < 1.0$).

RESULTS

Results will be presented in a similar format for all three tasks (Goldmann, Octopus, UFOV) in order to compare performance across the three measures. Performance as a function of age will be shown separately for each eccentricity. The slopes of the best-fitting lines will be compared at different eccentricities to determine whether sensitivity losses for older adults increase for more peripheral targets. Greater sensitivity losses, and/or a reduction in the ability to localize the peripheral target would be indicative of a restricted UFOV. In addition, performance on all three tasks will be evaluated to determine how these visual field measures relate to subjects' survey responses.

Static perimetry

Figure 2 illustrates the results of the Goldmann perimetry task; log luminance sensitivity is plotted as a function of age at four eccen-

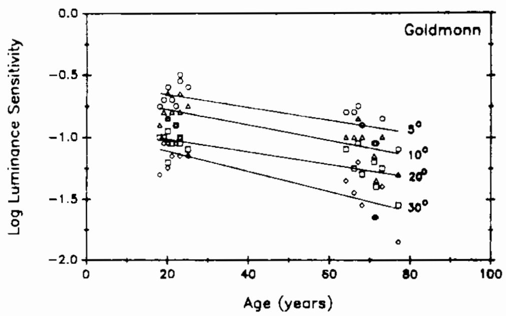

Fig. 2. Log luminance sensitivity from the Goldmann perimeter as a function of age. Best fitting lines are drawn for four eccentricities: 5 deg (open circles); 10 deg (open triangles); 20 deg (open squares) and 30 deg (open diamonds). The slopes and r^2 values for these functions are listed in Table 3.

Table 3. Slopes and r^2 Values for best fitting lines presented in Figs 2–5

Eccen. (deg)	Slope (dB/yr)	r^2
	Goldmann	
Full field	−0.061	0.608
5	−0.052	0.557
10	−0.062	0.615
20	−0.051	0.564
30	−0.082	0.676
	Octopus	
Full field	−0.090	0.552
0—10	−0.083	0.709
10—20	−0.085	0.672
20—30	−0.103	0.723
Eccen. (deg)	Slope (% correct/yr)	r^2
Full field	−0.0037	0.125
5	−0.0038	0.368
10	−0.0044	0.285
15	−0.0054	0.316
	UFOV (Center task and distractors)	
Full field	−0.0086	0.358
5	−0.0074	0.696
10	−0.0110	0.630
15	−0.0160	0.757

tricities. Slopes and r^2 values of the best-fitting lines are listed in Table 3. Consistent with previous reports (Brenton and Phelps, 1986; Jaffe *et al.*, 1986; Haas *et al.*, 1986; Johnson *et al.*, 1989), the average sensitivity loss is about 0.6 dB per decade. Also consistent with previous reports (Brenton and Phelps, 1986; Jaffe *et al.*, 1986, Haas *et al.*, 1986; Johnson *et al.*, 1989) is the finding that older adults exhibit substantially more inter-subject variability than do younger adults, particularly at the greater eccentricities. This increased variability could account for the fact that a significant increase in slopes with eccentricity was not observed for this task [$F(8, 136) = 1.55$, $P > 0.05$].

The results of the Octopus perimetry task are shown in Fig. 3, where dB of attenuation is plotted as a function of age for three ranges of eccentricity (0–10, 10–20 and 20–30 deg). The best-fitting lines are shown for each eccentricity, and slopes and r^2 values are listed in Table 3. In this task, the slopes of the best-fitting lines

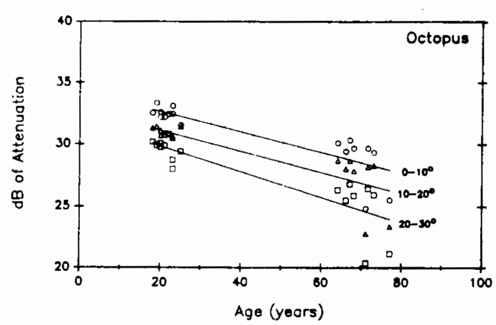

Fig. 3. Sensitivity (dB of attenuation) from the Octopus perimeter as a function of age for three ranges of eccentricity: 0–10 deg (open circles); 10–20 deg (open triangles) and 20–30 deg (open squares). The slopes and r^2 values for the best fitting lines are listed in Table 3.

did change with increasing eccentricity, with a slope of −0.083 for the 0–10 deg range and −0.103 for the 20–30 range [$F(2, 30) = 5.17$, $P < 0.05$]. Our findings of greater sensitivity loss for more peripheral targets is consistent with three previous reports (Haas *et al.*, 1986; Jaffe *et al.*, 1986; Johnson *et al.*, 1989). We did note, however, that our slopes tended to be slightly steeper than those in previous studies, probably due to the higher proportion of observers over age 70 in our sample.

In summary, measurements for our sample on both the Goldmann and Octopus perimetry tasks are consistent with other reports on normal observers. There is a loss of visual sensitivity with age, and this age-related loss appears to be more pronounced with increasing eccentricity when measurements are made with automated perimetry.

Useful field of view

Next we will consider how these same observers performed on the UFOV tasks, in which they localized suprathreshold targets in the presence of additional visual demands designed to mimic those present in everyday situations. Because our data were proportions (percent correct localization performance on the peripheral task) they were transformed for statistical purposes by taking the inverse sine of

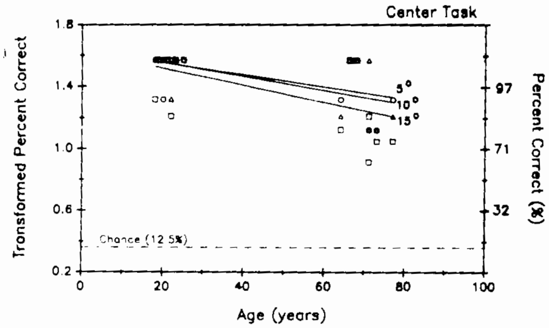

Fig. 4. Transformed percent correct (arc sine transformation) on the lefthand ordinate and percent correct on the righthand ordinate for the UFOV task with a center task and no distractors as a function of age for three eccentricities: 5 deg (open circles); 10 deg (open triangles) and 15 deg (open squares). Chance performance is shown by the dashed line at the bottom of the figure (12.5% on this task), and baseline performance is shown by the dotted line at the top of the figure. Slopes and r^2 values for the best fitting lines are presented in Table 3.

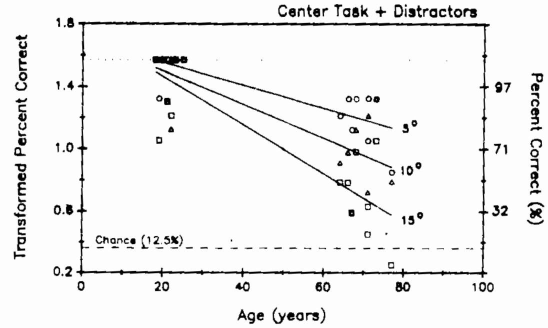

Fig. 5. Transformed percent correct (arc sine transformation) on the lefthand ordinate, and percent correct on the righthand ordinate, for the UFOV conditions with a center task plus distractors as a function of age for three eccentricities: 5 deg (open circles); 10 deg (open triangles) and 15 deg (open squares). Chance performance is shown by the dashed line at the bottom of the figure (12.5% for this task), and baseline performance is indicated by the dotted line at the top of the figure. Slopes and r^2 values for the best fitting lines are presented in Table 3.

the square root (Myres, 1972, p. 72). On this scale, chance performance (12.5%) corresponds to 0.36. Figure 4 illustrates for each eccentricity how performance changes with age when a center task is present (mean for conditions 5 and 7). The top dotted line indicates baseline performance (i.e. the mean of UFOV conditions 1 and 2 with neither a center task nor distractors). In those conditions, all observers performed the peripheral localization task with 100% accuracy at all eccentricities. Slopes and r^2 values for transformed percent correct localization as a function of age are listed in Table 3. A repeated measures ANOVA, with age as the sole between-groups variable, was performed on the transformed data. A significant center task × age interaction indicated that the presence of the center task had a greater effect on localization performance of the older observers [$F(2, 30) = 6.04$, $P < 0.01$]. Furthermore, this effect was significantly larger at greater eccentricities as indicated by a center task × age × eccentricity interaction [$F(4, 60) = 3.07$, $P < 0.05$]. Given perfect performance for all observers in our baseline conditions, these results illustrate that the inclusion of a central task restricts the field of view for older adults.

Figure 5 shows the effect on performance when distractors are added to the peripheral localization task and the central task is retained (mean of conditions 6 and 8). Slopes and r^2 values are also shown in Table 3. Baseline performance is again illustrated at the top of Fig. 5 by the dotted line. Consistent with the results of the center task alone conditions, a significant distractor × age interaction was found, indicating that the presence of distractors had a greater effect on the localization performance of older observers [$F(1, 15) = 66.73$, $P < 0.0001$]. This effect also increased with eccentricity as indicated by the distractor × age × eccentricity interaction [$F(2, 30) = 16.02$, $P < 0.001$]. Figure 5 dramatically illustrates how the useful field of view is reduced with age. In the distractor plus center task conditions older observers are near chance performance (indicated at the bottom of Fig. 5 with a broken line) at 15 deg eccentricity. In general, older adults were 20% worse than the younger adults on the task at 5 deg eccentricity, whereas they were 50% worse at 15 deg eccentricity.

Multiple regression analyses

A major question we wished to address was whether visual field measurements can predict the frequency with which older adults experience difficulty on everyday activities such as driving, walking and visual search. Before directly addressing this question we first examined the pattern of relationships between the major variables we evaluated. These variables included: performance on each static perimetry test (where sensitivity was averaged across the mean value at each eccentricity to yield an overall measure); performance on the UFOV conditions (also averaged across eccentricity); binocular letter acuity, and age.

A correlation matrix across all the variables indicated that intercorrelations among all the measures was very high. This is not surprising since every measure we examined has previously been found to vary with age. We chose the UFOV conditions with the highest zero-order correlation with survey responses to represent the UFOV task in our regression analysis. These were the center task with distractor conditions illustrated in Fig. 5. Although binocular letter acuity was significantly related to age, it was not significantly correlated with reported difficulty on either group of questions and thus it was not chosen for inclusion in the regression analyses.

The problem of multicollinearity among the predictors (they are all correlated with age and each other) was addressed by performing a hierarchical regression analysis which forces all the predictors to be evaluated simultaneously (Scialfa and Games, 1987). Performance measures on the Goldmann and Octopus tasks, the noise plus center task UFOV conditions, and age were regressed simultaneously on the survey scores associated with peripheral vision (Factor 1). Table 4 presents, for each variable, a beta weight, partial regression coefficient, and test of significance resulting from this analysis. In the first run we included all observers. Although collectively our four predictor variables accounted for 96% of the variance in the responses of these observers to Factor 1, the only significant predictor in the model was performance on the UFOV task ($t = 5.375$, $P < 0.001$). Age was the next best predictor, but was not significant with $P = 0.0792$.

In order to determine whether performance on the UFOV task was simply reflecting the large age difference in terms of responses to the questionnaire, we next performed the same regression analysis on only the older observers. Once again UFOV performance was the only significant predictor ($t = 3.82$, $P < 0.05$) and the four variables collectively accounted for 95% of the variance. Finally, we examined the performance of only the younger observers. In this case r^2 was not significant, and none of the variables predicted questionnaire responses. This reflects the fact that the younger observers did not have any difficulty in any of the tasks measured, and there was very little variance in their responses on the questionnaire (most young observers responded that they never had difficulty with any of the everyday activities described).

Table 5 illustrates the results of a similar analysis when responses to the light sensitivity and glare questions were used as the criterion. The only significant predictor for these questions was age ($t = 6.96$, $P < 0.001$) and the same four variables accounted for 94% of the variance in responses. When the analysis was repeated with only the older observers r^2 was no longer significant and none of the variables significantly predicted responses. Similarly, r^2 for the nine younger observers was not signifi-

Table 4. Regression models predicting visual speed/visual search difficulties

Variable	B	Partial	t	P
		Total model (17 observers)		
Age	0.06	0.484	1.981	0.0792
Goldman	−0.08	−0.006	−0.019	0.9848
Octopus	0.07	0.053	0.183	0.8581
UFOV	28.51	0.841	5.375	0.0002
$r^2 = 0.959$	$F = 70.966$		Signif. $F = 0.0000$	
		Older observers (8 observers)		
Age	0.339	0.151	1.181	0.3227
Goldmann	−7.860	−0.113	−0.879	0.4441
Octopus	0.045	0.009	0.071	0.9481
UFOV	31.040	0.490	3.820	0.0316
$r^2 = 0.95$	$F = 14.42$		Signif. $F = 0.0267$	
		Young observers (9 observers)		
Age	−0.153	−0.443	−1.284	0.2684
Goldmann	3.960	0.497	1.443	0.2226
Octopus	−0.107	−0.325	−0.943	0.3990
UFOV	3.324	0.212	0.616	0.5713
$r^2 = 0.524$	$F = 1.103$		Signif. $F = 0.4633$	

Table 5. Regression models predicting light sensitivity/glare difficulties

Variable	B	Partial	*t*	*P*
		Total model (17 observers)		
Age	0.199	0.4840	6.960	0.0000
Goldmann	4.767	0.0897	1.290	0.2212
Octopus	0.412	0.0824	0.119	0.2587
UFOV	0.695	0.0100	0.150	0.8829
$r^2 = 0.842$	$F = 48.761$		Signif. $F = 0.0000$	
		Older observers (8 observers)		
Age	0.56	0.707	1.733	0.1815
Goldmann	5.92	0.322	0.589	0.5972
Octopus	0.48	0.359	0.688	0.5520
UFOV	−6.07	−0.359	−0.665	0.5534
$r^2 = 0.65$	$F = 1.42$		Signif. $F = 0.4038$	
		Young observers (9 observers)		
Age	0.026	0.186	0.421	0.724
Goldmann	−2.694	−0.654	0.420	0.159
Octopus	1.148	0.655	0.183	0.149
UFOV	−1.820	−0.029	0.536	0.955
$r^2 = 0.656$	$F = 1.91$		Signif. $F = 0.2736$	

cant using these questions as the criterion. Thus, performance on the UFOV task specifically predicts difficulty in everyday tasks associated with visual search, mobility, and speed of processing. It should also be mentioned that when UFOV is deleted from the regression equation, age becomes a significant predictor for the visual speed/visual search difficulties as well. While performance on the Goldmann and Octopus are significantly correlated with age, they do not provide any additional information once age is used to predict responses.

We noted earlier in the results that the intercorrelations among the various UFOV conditions were quite high. In particular, the correlation between the distractor plus center task conditions (6 and 8) and the distractor without center task conditions (5 and 7) was 0.94. The correlation between the distractor plus center task conditions (6 and 8) and the distractor without center task condition (3) was also high ($r = 0.89$). Substituting any of the distractor conditions in the regression model in lieu of the original UFOV tasks does not substantially reduce r^2. Thus any of the UFOV conditions which incorporate distractors into the peripheral localization task appear to be good predictors of difficulty in everyday tasks associated with peripheral vision and a slowing of visual processing.

DISCUSSION

The results of this study are consistent with the hypothesis that older adults, in general, experience more difficulty in everyday situations involving visual search, distractors, and simultaneous use of foveal and peripheral vision. It is also apparent that they are quite aware of these problems (as indicated by their responses on the visual function survey). Thus an older patient reporting these types of visual difficulties to an eyecare specialist should not be an uncommon occurrence. The UFOV tasks, which were specifically designed to simulate visual field searches under more realistic everyday conditions, appear to be a viable way to measure the difficulties experienced by the older adult. Furthermore, our data imply that clinical visual perimetry, as typically carried out, underestimates older adults' problems with peripheral vision.

As stated earlier, results on both measures of static perimetry are consistent with other reports in the literature showing an age-related loss of sensitivity in the visual field. Our results indicate that the loss may accelerate after age 70, although further study of adults older than 70 yr is needed to confirm this finding.

Additionally, we noted that the slopes of the best fitting lines relating sensitivity to age became steeper with eccentricity in the Octopus task but not in the Goldmann task. There are several possible explanations for this finding. The psychophysical procedure used in the Goldmann may be more unreliable, in that there are no catch trials, and thus thresholds may be more susceptible to criterion effects causing greater variability problems. Another possibility is that the greater position uncertainty in the Octopus automated task (assessing 76 positions throughout the field rather than just the 9 positions along the 0–180 deg meridian) affected performance on peripheral stimuli more so than on those closer to fixation. Additionally, there is evidence that position uncertainty may be more of a problem for an older individual than a younger one (Cerella *et al.*, 1987).

Base on the results of both static perimetry tests we are confident that the observers in our sample had visual fields within the "normal limits" for their age, since their data is comparable to that of "normative studies" (Haas *et al.*, 1986; Jaffe *et al.*, 1986; Johnson *et al.*, 1989). Despite this apparent normalcy, the UFOV task has indicated a marked age-related loss in the diameter of the useful field of view within the central 15 deg; our earlier work has indicated that this loss extends at least out to 30 deg (Ball *et al.*, 1988).

One possible explanation for the age differences observed in these tasks is the low luminance levels employed. The two static perimetry tasks were conducted with a mean luminance of 10 cd/m^2, while the background luminance in the UFOV tasks was 0.03 cd/m^2. Leibowitz *et al.* (1955) have shown that radial localization accuracy is independent of luminance, provided the stimulus or stimuli are visible. Since all observers had error free performance on the UFOV task with no distractors and no center task, we are confident that the stimulus was at a suprathreshold level. Thus low luminance can be ruled out as the basis for differential performance in the two types of tasks.

We also do not believe that the poorer performance of the older observers on the UFOV tasks containing distractors can be accounted for by factors such as poor acuity, problems in fixation stability, eye movements, or age-related pupillary miosis. As noted in Ball *et al.* (1988), acuity is not related to radial localization errors for the range of acuities reported in this study. With respect to eye movements, it has been shown that visually healthy older observers achieve fixation stability comparable to their younger counterparts for the durations used in this study (Kosnik *et al.*, 1986). In addition, the brief exposure durations used in the present investigation were intended to minimize saccadic eye movements. Finally, with respect to varying pupil size, Sloane *et al.* (1988) have reported that age-related miosis, which reduces retinal illuminance in the older eye, is not related to observed sensitivity losses in spatial vision under the light levels tested in this study. They found, rather, that the miotic pupil tended to have a positive effect on the spatial vision of older adults, possibly due to its minimizing optical aberration and increasing depth-of-focus. We therefore do not believe that the miotic pupil is responsible for sensitivity losses in the perimetry tasks, or performance on the UFOV tasks.

In addition to known optical changes in the aging eye, it has been well documented that older individuals have a slower speed of perceptual processing (Kline and Szafran, 1975; Kline and Birren, 1975; Walsh, 1976; Walsh *et al.*, 1978; Walsh *et al.*, 1979). It has also been shown that the size of the functional visual field that can be searched in parallel within some short duration (<200 ms) varies with age (Ball *et al.*, 1988), as does the time required to perform various central tasks (Ball *et al.*, 1987). Since several of the questions on the survey are phrased in terms of taking longer to do things now than in the past, and having less confidence in your vision than you did previously, it is not surprising that older individuals would have difficulty with a visual search task presented at such a brief duration. Our results are consistent with those of Scialfa *et al.* (1987) who concluded that older adults take smaller perceptual samples from the visual scene and scan these samples more slowly. Thus given a limited amount of time, the size of the functional field would be smaller, in general, for an older individual.

Given a smaller functional visual field, it is important to consider how it would impact everyday experiences. There have been several attempts to link age-associated declines in visual field sensitivity and performance on everyday tasks. An area in which this approach has largely failed is in correlating age-related visual field loss to driving performance (Burg, 1967; 1968; Allen, 1970; Henderson and Burg, 1974; Council and Allen, 1974; Shinar, 1977). One exception to this is a large sample study ($N = 10{,}000$) by Johnson and Keltner (1986) who found that the small subset of drivers with severe binocular visual field loss (mostly older drivers) had accident and conviction rates twice as high as those with normal visual fields. No study to date, however, has established a link between the more subtle types of visual field loss (as with normal aging) and driving ability.

Older drivers, in general, have been found to have more traffic convictions and accidents and incur more fatalities per mile driven than any other age group (Planek, 1973; State of California Dept of Motor Vehicles, 1982; Transportation Research Board, 1988). The accident profile of the older driver is also more likely to include failures to heed signs, to yield the right of way, to turn safely, and more frequent junction accidents (Campbell, 1966; Moore *et al.*, 1982; Kline, 1986). Interestingly, all these activities involve the processing of information from the periphery. One reason why it may be difficult to establish relationships between perimetric measures of the visual field and performance in everyday activities such as driving, is that standard clinical perimetry seeks to minimize environmental factors typical under everyday conditions. For example driving, like many other everyday activities, involves more complex visual scenes with distracting stimuli and the simultaneous use of both foveal and peripheral vision.

It is not surprising that earlier research has failed to find a link between visual field loss due to aging, and performance on everyday tasks such as driving. First, perimetric measurements of the visual field do not appear to be tapping the nature of the difficulty older adults are having with these tasks. Rather than their difficulty being related to an absolute sensitivity loss, it is more likely that older adults' problems are related to complex visual skills, such as attending to both a focal and secondary task, and localizing a target amidst a visually cluttered environment. Another possible reason why research has failed to demonstrate a link between visual field loss and tasks such as driving, is that older drivers with functional vision problems are aware of their visual limitations and try to compensate for them by driving more slowly and avoiding peak traffic times. Given this type of strategy one would expect that accident records would underestimate the degree of visual difficulty older adults have while driving.

Avolio *et al.* (1986) have reported that performance on tasks involving target acquisition in the presence of visual clutter correlates with driving accident rates. Our data imply that this relationship may be even stronger for an older age group. The first component of the driving task, according to a recent analysis (Transportation Research Board, 1988) involves the sampling and registration of a visual event. Measures of the UFOV have shown that in general older individuals take smaller samples and are slower to process them. With respect to another important component of the driving task, recognizing and localizing the positions of various targets, we have found that while most older adults can localize a peripheral target as well as young adults when no distractors are present and there are no central task demands, the addition of these variables impacts the performance of far more older adults than younger adults (Sekuler and Ball, 1986; Ball *et al.*, 1988). These findings imply that, in general, the older driver would be more likely to experience visual difficulties.

As noted earlier, there is a high degree of variability among older individuals, both in their reported problems related to visual search and in their performance in UFOV tasks. Because the UFOV task is related to the frequency with which older adults report these problems, this task could be useful in identifying those individuals who are most debilitated. Furthermore, it has been previously shown that older adults' performance in UFOV tasks can be improved with modest amounts of practice (Sekuler and Ball, 1986; Ball *et al.*, 1988). Thus, these studies suggest that individuals with serious impairments could be rehabilitated. Finally, it remains for us to establish a link between improved performance in our laboratory-simulation task, and performance in the real-world activity itself.

Acknowledgements—We would like to thank Daniel Roenker, Michael Sloane, David Ball and Harold Skalka for statistical and editorial consultation. This work was supported by National Institutes of Health Grants AG-05739, AG-04212, AG-RYO1251 and EY-06390.

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