Age-related changes in the functional visual field

Coeckelbergh, T.R; Cornelissen, F.W; Brouwer, W.H.; Kooijman, A.C

Published in:
The Journals of Gerontology. Series B: Psychological Sciences and Social Sciences

Publication date:
2004

Journal of Gerontology: PSYCHOLOGICAL SCIENCES
2004, Vol. 59B, No. 1, P11–P18

Age-Related Changes in the Functional Visual Field: Further Evidence for an Inverse Age × Eccentricity Effect

Tanja R. M. Coeckelbergh,[1] Frans W. Cornelissen,[1] Wiebo H. Brouwer,[2] and Aart C. Kooijman[1,3,4]

[1]Laboratory of Experimental Ophthalmology, University of Groningen, The Netherlands.
[2]Department of Neuropsychology and Gerontology, University of Groningen, The Netherlands.
[3]Department of Ophthalmology, University Hospital Groningen, The Netherlands.
[4]Visio, Dutch National Foundation for the Visually Impaired and Blind, Groningen, The Netherlands.

We assessed the performance of younger and older individuals by using the Attended Field of View test, a visual search task in which eye movements were allowed. When adjusting for slower processing in the older age group by log transformation, we observed significant effects of age, eccentricity, and Age × Eccentricity. Contrary to most previous findings, the Age × Eccentricity effect was "inverted" in that the difference between the age groups decreased as a function of eccentricity. The finding that the eccentricity effect of younger individuals was larger than that of older individuals was caused by large age-related differences in sensitivity for centrally located targets, even though differences with regard to foveal resolution were controlled. The results further indicated that, given a brief amount of time, older persons could process a smaller field of view than younger persons. Consequently, older persons were forced to resort to serial scanning for a larger part of the display, whereas younger persons could process a larger area in parallel.

OLDER people report difficulties with visual distractors more often than younger people. Examples are trying to locate a friend in a crowd or trying to read a street sign that is surrounded by other street signs (Sekuler & Ball, 1986, citing a study by Kosnik, Sekuler, & Rasinski, 1985). In an attempt to study these difficult visual situations in older adults, Sekuler and Ball (1986) designed the Useful Field of View (UFOV) test, a radial localization task that measures how well a single, randomly positioned, and briefly presented target can be localized in the presence of distractors both with and without a secondary central task. The UFOV is defined as the visual area in which useful information can be acquired in a single glance, that is, without eye and head movements. Ball and colleagues (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley, & Beard, 1990; Sekuler & Ball, 1986) observed that, in comparison with that of younger adults, the UFOV of older adults was constricted.

In this article, an alternative test is introduced to assess the functional visual field. The rationale for this new test lies primarily in the use of eye movements. The UFOV test was developed to mimic specific problems seen in older adults, such as reading street signs that are surrounded by other street signs. Such a task involves the identification of a target under free-viewing conditions. Neither of these characteristics is reflected in the UFOV because it assesses peripheral localization at very short presentation times that preclude eye movements. The use of eye movements is an inherent part of everyday life and may become particularly important in case of visual field defects. We therefore developed a test that allowed eye movements and termed it the Attended Field of View (AFOV) test. It makes use of a visual search paradigm. Participants are instructed to identify a target presented at various eccentricities and embedded amidst a large number of distractors. Participants are allowed to make head and eye movements. Hence, the AFOV assesses the functional visual field but abolishes the single-glance criterion as defined in the UFOV. The present article investigates the effect of age on the functional visual field when eye movements are allowed. The effect of age on the AFOV test is compared with the effect of age in studies on the functional visual field when eye movements are not allowed.

Studies regarding the effect of age on the functional visual field report conflicting results. Several studies on the UFOV have shown a disproportionate increase in error rates at greater eccentricities in older persons, which has led to the understanding that the UFOV is constricted in older adults (Ball et al., 1988, 1990; Sekuler & Ball, 1986). Other researchers, however, have questioned this constriction of the UFOV as a function of age. Seiple, Szlyk, Yang, and Holopigian (1996), for example, argued that constriction of the UFOV is not unique to older adults. Using a condition comparable with that in the study by Ball and colleagues (1988), they observed an eccentricity-independent increase in localization errors as a function of age. Older participants performed worse than the younger participants, and error rates increased in both age groups as a function of eccentricity. However, in contrast to the reports by Ball and colleagues (1988), the difference between the age groups remained constant across the field of view. Sekuler, Bennett, and Mamelak (2000) are of the same opinion. They compared performance under a divided-attention condition (central letter-recognition task and a peripheral localization task) as well as a focused-attention condition (only a peripheral localization task) in a younger and an older age group. In the focused-attention condition, the effects of eccentricity, age, and Age × Eccentricity were significant. In the divided-attention condition, however, only the effect of age was significant. There was neither an increase in errors as a function of

Table 1. Mean and Range of Vision Parameters in Experiments 1 and 2

Parameter	Young Group	Older Group	
		Experiment 1	Experiment 2
Visual acuity (DN)	1.3 (0.5–2.0)	1.0 (0.6–2.0)	1.0 (0.6–1.6)
Contrast sensitivity (HFA, dB)	38.70 (36.5–41.5)	33.30 (32.5–35.5)	33.36 (27.5–35.5)
Contrast sensitivity (GECKO, log)	2.05 (1.8–2.15)	1.78 (1.51–2.15)	1.84 (1.68–2.15)

Notes: For the young group, only Experiment 1 is shown; $n = 7$. For the older group, $n = 7$ for both Experiments 1 and 2. DN = decimal notation; HFA = Humphrey Field Analyzer; GECKO = Groningen Edge Contrast Chart. Ranges are given parenthetically.

eccentricity nor an Age × Eccentricity interaction. The authors concluded, therefore, that the younger and older observers had equivalent UFOV sizes, but that the older adults processed information less efficiently in that area. McCalley, Bouwhuis, and Juola (1995) and Cornelissen and Kooijman (2000) described still another pattern of results. They observed that older persons have relatively more problems identifying central targets and fewer problems identifying peripheral targets.

The present study investigates the effect of age on the functional visual field when the AFOV paradigm is used. The effects of age and eccentricity are studied and related to the three views as described herein. The performance of younger and older healthy adults is investigated here as a first step in the standardization of the approach and the development of age-related norms for individuals with visual field defects. It is hypothesized that persons with visual field defects can compensate for their visual impairment by making eye and head movements. This hypothesis is based on the supposition that a test that allows eye movements renders a better estimate of the functional visual field than a test that does not allow eye movements.

Experiment 1: Assessing the Effect of Age on the AFOV—Methods

Participants

Seven young (range: 22–28 years) and seven older (range: 58–78 years) individuals participated in the first experiment. Participants were recruited by an advertisement in local papers or billboards. All participants gave their informed consent prior to participation. The younger age group consisted of four women and three men; the older age group consisted of three women and four men. Visual acuity, contrast sensitivity, and visual field measures are reported in Table 1.

Visual acuity was measured by use of a Bailey-Lovie chart (Bailey & Lovie, 1976) at a distance of 3.8 m. Visual acuity is expressed as decimal notation in the text and as log MAR in the statistical analyses. Contrast sensitivity was measured by use of the Groningen Edge Contrast Chart (GECKO; Kooijman, Stellingwerf, van Schoot, Cornelissen, & van der Wildt, 1994) at a distance of 3.8 m. Visual field perimetry was performed by use of the Central 10-2 and Central 24-2 programs of the Humphrey Field Analyzer (HFA). All tests were carried out binocularly because performance on the AFOV test was also assessed binocularly. Mean visual acuity was within (near-) normal limits for all participants. The visual acuity of one of the younger participants was 0.5. When the results on the AFOV were reanalyzed without the scores of this individual, they did not change. It was concluded, therefore, that the lower visual acuity did not affect performance on the AFOV and the individual's scores were not removed from further analysis.

Apparatus

Stimuli were presented on a 20-in. (50.8 cm) Trinitron monitor controlled by an Apple Macintosh computer. Custom software was written for presenting stimuli by use of some of the routines from the VideoToolbox (Pelli, 1997). Participants viewed the screen from a distance of 57 cm. Viewing distance was kept constant by a fixed chair and regular measurements of the distance between the eyes and the screen. A chinrest was not used because the pilot study showed that it kept participants from moving their eyes and head.

Materials

The display consisted of 24 distractors (O) and a single target (a C with its gap oriented in one of four directions: up, down, left, or right). The distractors and the target measured 0.5° in diameter. The target gap was 0.1°. The stimuli were positioned on a grid along eight radii (oriented at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°) and at three eccentricities (4°, 8°, and 12°). One element was positioned in the center of the display (0°). The display consisted of white stimuli on a gray background (50% contrast). An example of the display is shown in Figure 1.

The time that the participants needed to recognize and localize the target to achieve criterion performance (which was set at 67% correct target identification and localization) was measured. For each position in the stimulus display, a separate and independent staircase was run to estimate the required presentation time at that position. The decision rule for increasing and decreasing the duration was as follows: Whenever the participant made a correct response, the duration (for that position) was decreased, and when the participant made an error, the duration was increased (one down–one up rule). The duration never was the same on any two subsequent trials. By using a weighted up–down method, that is, having a larger increase during errors than (absolute) decrease during correct responses, the staircase converges on the 67% correct point (delta– to delta+ ratio of 1:2; Kaern, 1991).

Initial presentation time for the first trial was 1 s. For this initial presentation time to be adapted to the performance of the participant, a separate and independent Quest procedure (Watson & Pelli, 1983) was used to simultaneously estimate a mean threshold presentation time irrespective of the position of the target stimulus. The current estimate of this mean response was used as the initial presentation time at a position.

For the staircases run for each separate position, 12 reversals were determined, of which the first 2 were ignored. Next, error and correct response-related reversals were sorted and averaged separately, after the highest and lowest values were removed from each set. The final value is the average of the mean error and correct response reversals (and was thus based on 6 reversals). The highest and lowest values were removed to prevent occasional outliers from influencing the results. The reason for separately removing outliers from the error and correct response-related reversals is that this prevents one, for example, from removing only outliers related to error reversals. As the actual threshold is assumed to be the mean of the error and correct response-related reversal values, this is undesirable.

This method allowed us to evaluate the participants at the same criterion level of performance so that the results were not affected when different participants made different speed or accuracy trade-offs. Measuring threshold presentation times also eliminated the confounding effect of differences in motor response time, because the response mode was not based on reaction time. Participants responded by indicating the direction of the gap. Reaction times of the responses were not monitored.

Procedure

A central fixation point was shown before the presentation of the display. Participants initiated the presentation of the next display by pressing a mouse button while looking at the fixation point. The fixation mark disappeared before the display was shown. Participants were instructed to look for an open circle and to indicate the position of the target and direction of the gap. They used the computer's mouse to point at a marker that indicated a particular position and gap direction. The stimuli were presented with varying presentation times (range: 8 ms–10 s). A staircase procedure was used to determine the presentation time necessary to reach a 67% correct criterion for each of the 25 possible target positions. Presentation time of the distractors was always identical to the presentation time of the target. The test was performed binocularly, and the participants were allowed to make head and eye movements in order to accomplish the task. Eccentricity in relation to our paradigm, therefore, refers to the distance to the initial fixation point.

Log Transformation

Results in this article are reported in terms of sensitivity, which we define as 1 divided by the presentation time (in seconds) required to correctly locate and identify the target. The data were log transformed because of two main reasons. First, we were interested in relative differences. A difference of, for example, 10 ms is of much more importance when we are comparing 20 ms to 30 ms than when we are comparing 820 ms to 830 ms. Second, we wished to remove the effect of general slowing. As the effects of eccentricity and general slowing are thought to be multiplicative (e.g., Birren, Woods, & Williams, 1980; Cerella, 1985; Salthouse, 1988), the difference between the age groups would be disproportionately large in the periphery on a linear scale. If a relation is multiplicative, it makes much more sense to think of it as an additive system on a logarithmic scale (Sokal & Rohlf, 1995).

Statistical Analysis

Only the 4°, 8°, and 12° eccentricity data were included in the statistical analysis. This was done for two reasons. First, there was only a single measurement for 0° eccentricity compared

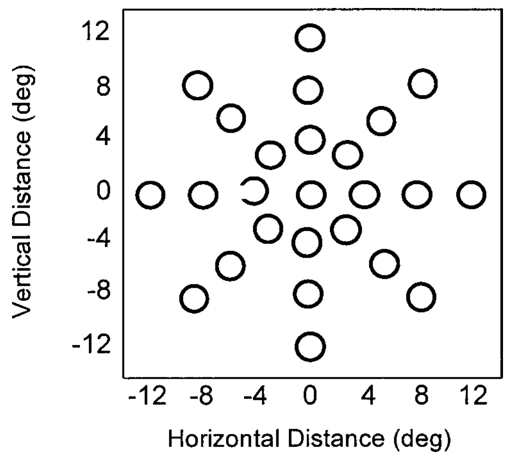

Figure 1. Attended Field of View display as used in Experiments 1 and 2. In the actual experiments, white targets were presented on a gray background (50% contrast). The participant was instructed to look for an open circle and indicate its position and the direction of the gap. Eye and head movements were allowed. A staircase procedure determined the threshold presentation time at which the participant responded correctly in 67% of the trials. Presentation time varied from 8 ms to 10 s.

with eight for the other three eccentricities, which made it difficult to include this value into the repeated measures analysis of variance. Second, younger participants made hardly any errors when locating and recognizing the central target at the shortest presentation time possible on our monitor (1 frame at 120 Hz). Hence, we may have underestimated the sensitivity of the younger participants.

Results

Functional Visual Field

Figure 2 plots the log sensitivity (= 1/presentation time) of the older and younger participants as a function of eccentricity. Mean log sensitivity, standard error of the mean, and linear threshold presentation times are listed in the Appendix. On average, older participants required approximately 4 times (~0.6 log units) longer presentation times than younger participants to correctly locate and recognize the target (older participants, 0.36 log sensitivity = 437 ms vs. younger participants, 0.96 log sensitivity = 109 ms). A statistical analysis confirmed that this age difference was significant, $F(1, 12) = 46.98$, $p < .001$. The second main effect that could be observed was that sensitivity for both younger and older participants declined sharply with increasing eccentricity, $F(2, 24) = 283.10$, $p < .001$. The interaction between age and eccentricity was also significant, $F(2, 24) = 16.56$, $p < .001$. As we can see in Figure 2, the decline in sensitivity with eccentricity was larger for the younger than for the older participants. The difference between the younger and the older participants was approximately a factor of 7 (~0.8 log units) at 4° of eccentricity, but only a factor of 2 (~0.35 log units) for targets at 12° of eccentricity. Although not included in the analysis, the 0° data were in line with this finding.

Vision

Table 1 shows that, although within normal limits, contrast sensitivity (as assessed with the HFA and GECKO) of older

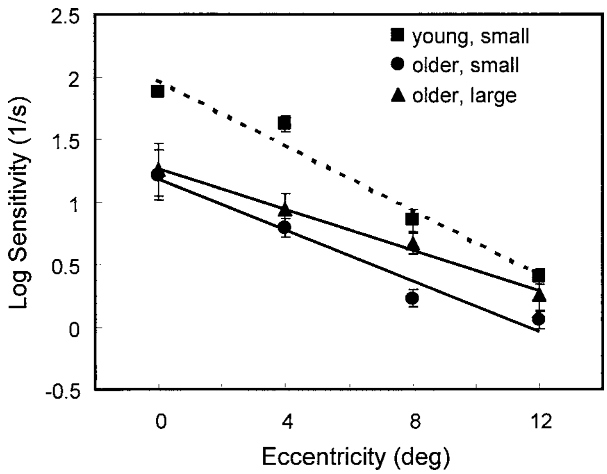

Figure 2. Log sensitivity (=1/threshold presentation time) as a function of eccentricity. Error bars indicate standard error of the mean. Squares represent data of younger participants with small stimuli (Experiment 1), circles represent data of older participants with small stimuli (Experiment 1), and triangles represent data of older participants with large stimuli (Experiment 2). A small stimulus subtended 0.5° (diameter) with a target gap equaling 0.1°; a large stimulus subtended 1.0° (diameter) with a target gap equaling 0.2°.

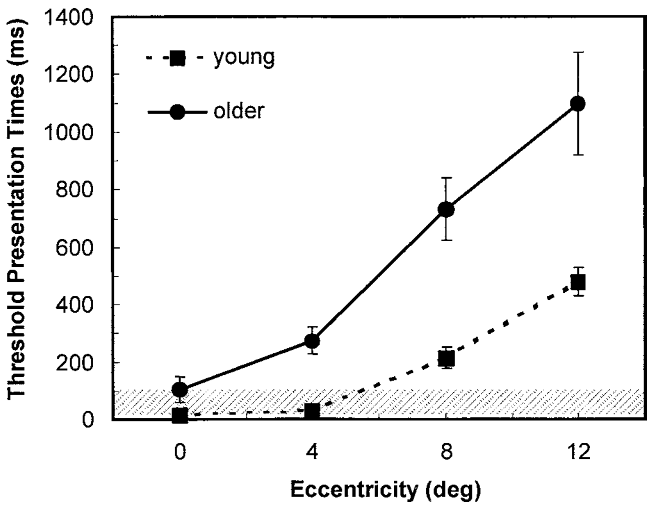

Figure 3. Linear threshold presentation times as a function of eccentricity and age. Error bars indicate standard error of the mean. The gray area represents the 100-ms presentation time. This presentation time is comparable with the stimulus durations used in studies on the Useful Field of View test and precludes eye movements. The area that participants could process without making eye movements (i.e., the useful field of view) was much smaller for the older group than for the younger group. The younger individuals could process up to almost 6° within 100 ms, whereas older individuals could only process the central target.

participants was significantly reduced compared with that of the younger participants: HFA, $F(1, 12) = 54.20$, $p < .001$, and GECKO, $F(1, 12) = 6.61$, $p < .05$. Visual acuity was also lower, but this effect was not significant, $F(1, 12) = 1.34$, *ns*.

Linear Data

So far, only log-transformed data have been analyzed. This type of approach tends to obscure certain aspects of performance. In many real-world, real-time conditions such as traffic or vocation, for example, absolute time differences are highly relevant. The linear threshold presentation times are plotted in Figure 3 as a function of age and eccentricity. We can see that the threshold presentation times for older participants are disproportionately high in the periphery. These results corroborate previous findings of a constricted UFOV in older adults. The area that older adults could process at 100 ms, for example, was much smaller than that processed by younger adults. In fact, the UFOV of younger adults extended to almost 6° when they could view the field for 100 ms, whereas older adults could only process the central stimulus in this brief amount of time.

Experiment 2: Test of Foveal Performance in the Older Group

The reduced contrast sensitivity and the slightly lower visual acuity of the older group indicate that vision was not equivalent in the two age groups. Moreover, the lower visual performance of older individuals might have caused the decreased performance for central targets. If so, we would expect that increasing the size of the targets would increase the sensitivity for central targets in the older age group and bring the eccentricity function of the older group more in line with that of the younger group. This hypothesis was tested in Experiment 2.

Methods

Participants

Seven older individuals (age range: 57–76 years) participated in this experiment. They had not participated in Experiment 1. They were recruited by means of advertisements in local papers or billboards. The group consisted of two women and five men. Informed consent was obtained from each participant. Visual acuity, contrast sensitivity, and foveal sensitivity were assessed as described in Experiment 1 and are presented in Table 1.

Apparatus, Materials, and Procedure

The materials and test procedures resembled those of Experiment 1, but the size of the targets and distractors was increased to 1.0° and the size of the gap was increased to 0.2°.

Results

The results of Experiments 1 and 2 are plotted in Figure 2. Mean log sensitivity, standard error of the mean, and linear threshold presentation times are listed in the Appendix. The data of older individuals with large stimuli were compared with those of older individuals with small stimuli from Experiment 1. Log sensitivity for large targets was higher than log sensitivity for small targets, $F(1, 12) = 4.64$, $p = .05$, indicating that large targets were easier to detect than small targets. The eccentricity effect remained, $F(2, 24) = 102.72$, $p < .01$. Contrary to our hypothesis, the effect of stimulus size was related to eccentricity as indicated by the significant Size × Eccentricity interaction effect, $F(2, 24) = 4.87$, $p < .05$. Increasing the size of the stimuli had very little effect on foveal performance but a substantial effect on peripheral performance.

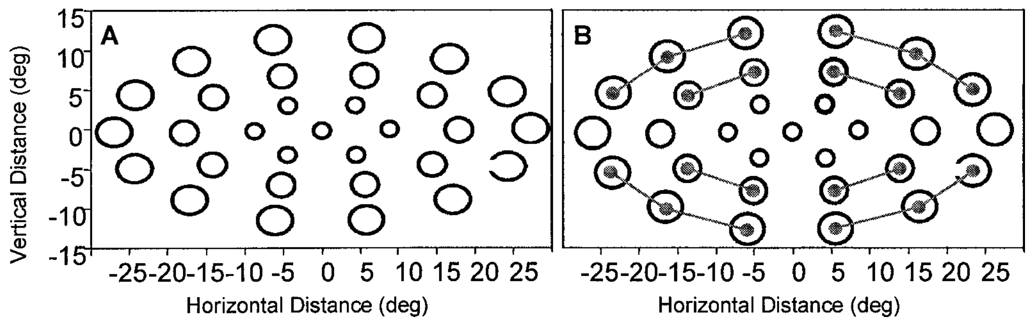

Figure 4. (**A**) Depiction of an example of the Attended Field of View stimulus as presented to the participants in Experiment 3. In the actual experiment, white targets were displayed on a gray background (50% contrast). Six positions per ring were analyzed (**B**): some positions were pooled and analyzed as one position. The pooled positions are connected with a gray line. The participant was instructed to look for an open circle and subsequently indicate the direction of the gap. Eye and head movements were allowed. A staircase procedure determined the threshold presentation time at which the participant responded correctly in 67% of the trials. Presentation time varied from 8 ms to 10 s.

It was therefore concluded that foveal sensitivity in the older group was not an important factor in limiting the performance for central targets in Experiment 1.

Experiment 3: Increasing the Size of the Objects as a Function of Eccentricity

In order to draw valid conclusions with regard to age-related attentional differences, confounding between vision and attention must be avoided. The influence of foveal sensitivity was investigated in Experiment 2. In Experiment 3, the stimulus size was increased with eccentricity in an attempt to reduce the influence of visual factors such as reduced spatial resolution in the periphery.

Methods

Participants

Thirty-four volunteers participated in this experiment. They were recruited by an advertisement in a local paper. Nineteen men and 15 women participated in this experiment. All participants scored well above a predefined cutoff score on a cognitive screening test (Mini-Mental State Exam; Folstein, Folstein, & McHugh, 1975). Scores ranged between 23 and 29. Individuals were allocated to one of four age groups: Group 1, 31 to 40 years of age ($n = 6$, $M = 35$ years, and $SD = 4$ years); Group 2, 41 to 50 years of age ($n = 13$, $M = 45$ years, and $SD =$ 3 years); Group 3, 51 to 60 years of age ($n = 8$, $M = 53$ years, $SD = 2$ years), and Group 4, older than 60 years of age ($n = 7$, $M = 68$ years, $SD = 4$ years). None of the individuals had participated in Experiments 1 and 2. All individuals reported good ocular health. This was confirmed either by a visual acuity test (Bailey–Lovie chart, $M = 1.1$, $SD = 0.3$) or a near visual acuity test. In the near visual acuity test, the minimal size of the target gap was determined for each individual at a distance equal to the test distance. The minimal gap size of the target as determined by the staircase procedure was smaller than that of the stimuli in the AFOV test for all individuals.

Apparatus

The apparatus was similar to the one used in Experiments 1 and 2, but viewing distance was 30 cm.

Materials

Thirty-one stimuli were arranged in three elliptical rings around a central stimulus. The visual angle of the display was 60° horizontally and 24° vertically. The display consisted of white stimuli on a gray background (50% contrast). No stimuli were presented on the vertical axis. The arrangement of the stimuli is presented in Figure 4A. Although 31 stimuli were presented, only 19 positions were tested. Three stimuli per quadrant were pooled in the outer ellipse, and two stimuli per quadrant were pooled in the middle ellipse. In this way, six positions were tested per ellipse, as shown in Figure 4B.

The size of the stimuli was determined by eccentricity. Object size for the outer two rings was gauged by the decline in the average performance by younger and older participants in Experiment 1. The target size was 1.4° for the center target and first ellipse, 1.9° for the second ellipse, and 2.4° for the outer ellipse. The stimuli were presented with varying presentation times (range: 8 ms–10 s). With the use of a staircase procedure, the presentation time at which the participant could correctly identify the target in 67% of the trials was determined for each of the 19 positions.

Procedure

The participant was instructed to locate the open circle (C) among 30 closed circles (O) and subsequently indicate the direction of the gap (left, right, top, or bottom of the circle). The position of the target was not requested in order to minimize test duration. Eye and head movements were allowed after the fixation marker had disappeared.

Statistical Analysis

Results were first analyzed by use of a General Linear Model repeated measures procedure on the log sensitivity data, which was equal to log(1/presentation time), with position of the target (center, Ellipse 1, Ellipse 2, and Ellipse 3) as a within factor and age group (1–4) as a between factor. The Geisser–Greenhouse correction was used in case of violations of the sphericity assumption.

Results

Mean threshold presentation times are plotted as a function of position and age group in Figure 5. Mean log sensitivity,

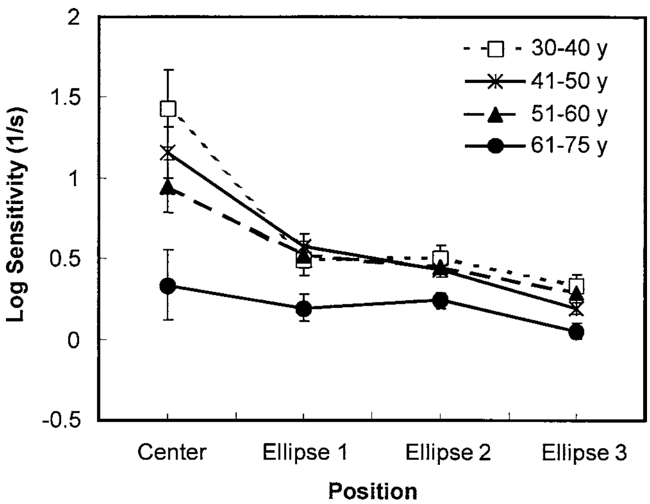

Figure 5. Log sensitivity (=1/threshold presentation time) data on the scaled Attended Field of View test as a function of ellipse (eccentricity) and age. The inverse Age × Eccentricity effect persisted, as did the effect of eccentricity and the effect of age. Post hoc analyses revealed that the effect of age was significant between the oldest group and the three younger groups. The differences between the three younger groups were not significant.

standard error of the mean, and linear threshold presentation times are listed in the Appendix. The results indicated that older adults needed longer presentation times to detect the target than younger adults, $F(3, 30) = 8.15$, $p < .01$. A post hoc analysis (Bonferroni multiple comparisons) indicated that the oldest group (>60 years of age) differed significantly from the other age groups ($p < .05$), whereas the three younger age groups did not differ significantly from each other. Threshold presentation times varied as a function of position, $F(1.5, 44.8) = 36.83$, $p < .01$, indicating that the eccentricity effect persisted despite the scaling of the stimuli. The effect of eccentricity differed as a function of age group: Age × Position interaction, $F(4.5, 44.8) = 2.65$, $p < .05$. Visual inspection of Figure 5 indicates that the eccentricity effect was larger for the three younger groups than for the oldest group.

Discussion

In the present study we investigated age-related effects on a visual search task under free-viewing conditions. We introduced the AFOV test to assess the time needed to identify targets in different positions of the field when eye movements were allowed. We excluded differences between the age groups, with regard to manual motor responses and general slowing, from influencing results and conclusions by log-transforming the data and by using a response mode that was not based on reaction times.

The results showed significant age and eccentricity effects. In general, older participants needed longer presentation times to detect the target than younger participants. All participants were faster to detect a central target than a peripheral target. A significant interaction effect was observed between age and eccentricity, indicating that the difference between the two age groups was largest in the central area. We termed this interaction effect an ''inverse'' Age × Eccentricity effect because the difference between the age groups decreased as a function of eccentricity. Stated otherwise, the eccentricity effect of the older group was smaller than that of the younger group. To exclude the possibility that differences in foveal resolution between the two age groups might have confounded attentional processes, we enlarged all stimuli for a separate sample of older individuals in the second experiment. This manipulation did not affect older individuals' performance in the central area. In the periphery, however, sensitivity for larger stimuli was higher than for small stimuli and almost equaled sensitivity values of the younger group for small stimuli (Figure 2). In the third experiment, we increased the size of the stimuli as a function of eccentricity to minimize effects of reduced spatial resolution in the periphery. The Age × Eccentricity interaction remained (Figure 5).

An inverse Age × Eccentricity interaction was first reported by Cornelissen and Kooijman (2000) in their comment on the study by McCalley and colleagues (1995), who reported that older individuals performed inferiorly in the central area when no positional cue was present. Their hypothesis was that individuals concentrated on an extracentral space rather than the central area itself, assuming that a target in the central area would ''pop out'' immediately. They further stated that this pop-out effect was not successful in the older group, because of, for instance, a decreased foveal sensitivity. The strategy to concentrate on extracentral space might have been used by the older adults in the present study too. Yet, decreased foveal resolution does not explain why this strategy failed as the effect remained when stimuli were presented well above the acuity threshold level (Experiment 2). Other visual factors might also be involved. Crowding, for instance, might have played a role because the central stimuli are flanked more than the peripheral items. The effect of age on crowding in general and in the AFOV test in particular still remains to be investigated.

The conclusion of the present study stating that older adults are less affected by eccentricity than younger adults is not in accordance with some previous conclusions. Ball and colleagues (1988, 1990) reported an increasing difference between age groups with increasing eccentricity. Seiple and associates (1996) and Sekuler and associates (2000) reported an almost equivalent difference between the age groups at all eccentricities. The discrepancy between the studies may be caused by differences in the experimental design, statistical techniques, or control of confounding factors. The effects of logarithmic transformation, backward masking, dual tasks, free viewing, and scaling are discussed in the following paragraphs.

Log Transformation

The main difference between the present study and the aforementioned studies is the logarithmic transformation. Our data were log transformed to study relative differences and to control for a general slowing of the older age group. Moreover, as data were not normally distributed and as variances differed by more than a factor of 4 (Howell, 1992), the analysis of variance assumptions were clearly violated and (log) transformation was required. (As the reader may wonder what the results would have been like if the untransformed linear data were analyzed, we reanalyzed the raw data despite the fact that assumptions of normality and homogeneity of variance were violated. The untransformed linear data are presented in the Appendix table.

In agreement with the log-transformed data, linear data clearly indicated that older persons needed longer presentation times to detect the target than younger persons. Likewise, all persons needed longer presentation times when eccentricity increased. Unlike log-transformed data, the Age × Eccentricity effect did not reach significance, although results of the first experiment hinted at a ''regular'' Age × Eccentricity effect.)

The log-transformed data showed that the eccentricity effect was larger for young adults than for older adults. This effect is largely caused by age-related differences in sensitivity to centrally located targets. In Experiment 1, older individuals needed 61 ms to detect the central target, whereas younger individuals needed only 13 ms. These threshold presentation times were too short to allow eye movements, and it was therefore concluded that both age groups could process the central target in a single glance (i.e., within one fixation). It remains unclear why older adults needed longer threshold presentation times than young adults for the central target. It seems unlikely that decreased foveal resolution has caused this effect, as it remained when stimuli were enlarged. As reported before, other factors such as an increased tendency to attend to extracentral space by older individuals (McCalley et al., 1995) or increased crowding effects might have played a role.

The inverse Age × Eccentricity effect might further be explained by different search strategies of the age groups. Linear data showed that the area that older adults could process at presentation times of 100 ms (equivalent to presentation times used in many UFOV studies) was smaller than that of younger adults. Older individuals could only process the central stimulus when eye movements were precluded, whereas younger individuals could process up to almost 6°. We deduced from this finding that the UFOV of older adults is smaller than that of younger adults. Older adults are thus forced to scan a larger part of the field serially. Moreover, as during subsequent fixations they could process only a small area, they needed more fixations than younger adults to search the whole field of view. On the basis of these different search strategies, increasing age-related differences would be expected in the periphery. However, we observed a much smaller age-related difference for peripheral targets than for central targets. These data suggest, therefore, that older individuals' serial scanning ability remained relatively intact.

As we did not measure the participants' eye movements, we cannot be sure about the specific strategy the participants used nor about the differences between older and younger individuals in their use of eye movements. Scialfa, Thomas, and Joffe (1994) showed in their experiments that older persons made two to three times as many saccades during search as younger persons. This finding is in line with the interpretation of our results. Although eye movements may be at the basis of the present results, there are some indications that the inverse eccentricity effect is not dependent on eye movements. Cornelissen and Kooijman (2000) noted that the effect was also present in the data of McCalley and colleagues (1995). Because of the short presentation time used in the study of McCalley and colleagues (1995), no eye movements could be made and, therefore, eye movements could not be at the basis of the inverse Age × Eccentricity effect in this study. Clearly, more investigation is needed on the effect of age on eye movement behavior while a person is performing visual search tasks.

Backward Masking Screen

We did not use a backward masking screen. Seiple and associates (1996) reported that error rates were higher for conditions with backward masking than for conditions without a mask and that this difference increased as a function of eccentricity. The absence of a mask, then, might have caused the diminished eccentricity effect seen in the present study. However, because Seiple and associates (1996) did not report an interaction effect with age, it remains unclear why the diminished eccentricity effect was observed for just the older participants.

Dual Task

Studies often report results of divided attention conditions in which participants have to perform a central and a peripheral task concurrently (Ball et al., 1988, 1990). The present study did not make use of a dual task. Ball and colleagues (1988, 1990) reported that the presence of a central task had a greater effect on the localization scores of older participants and that the difference between the age groups increased as a function of eccentricity. Because the effect of the concurrent central task was most evident for the older individuals in the periphery, its absence might explain the better-than-expected peripheral performance of the older group in the present study. However, this assumption is countered by the study by Sekuler and associates (2000), who observed an Age × Eccentricity effect in the localization task only and not in the divided attention condition.

Free-Viewing Paradigm

The present study used a free-viewing paradigm, whereas most of the earlier studies used very short presentation times in order to prevent eye movements (e.g., 90 ms by Ball et al., 1988, 90 ms by Seiple et al., 1996, 67 ms by Sekuler et al., 2000, and 100 ms by McCalley et al., 1995). Carrasco, Evert, Chang, and Katz (1995) reported an eccentricity effect not only under a free-viewing condition but also under a fixed-viewing condition (104 ms) and a fast-fixed-viewing condition (62 ms). In other words, the eccentricity effect seen in their study persisted irrespective of the presentation time. Results of the present study imply that short presentation times put older individuals at a disadvantage and that removing the time constraints diminishes the eccentricity effect in this group.

Scaling

The final difference between the present and most of the earlier studies relates to the scaling of stimuli. Scaling stimuli with increasing eccentricity should compensate for decreased peripheral acuity. McCalley and colleagues (1995) reported that the (linear) Age × Target location effect disappeared when the stimuli were scaled. However, as noted by Cornelissen and Kooijman (2000), the results of McCalley and colleagues suggested an overcompensation for eccentricity, and, when logarithmically analyzed, the inverse Age × Eccentricity effect persisted. Wolfe, O'Neill, and Bennett (1998) showed that, although scaling might reduce the eccentricity effect, it does not remove the effect entirely. It remains unclear, therefore, whether the difference between the present and the earlier studies can be attributed to the use of scaling only.

Summary

In summary, we examined performance on a visual search task in which participants were allowed to make eye movements. When we made an analysis in a logarithmic fashion in order to eliminate the influence of general slowing, we consistently found an inverse Age × Eccentricity effect. That is, eccentricity had a smaller effect on older participants' performance than on younger participants' performance. This effect can be attributed to large age-related differences in sensitivity for centrally located targets. The results further indicated that, given a brief amount of time, older individuals processed a smaller field of view than younger individuals. Consequently, older individuals were forced to resort to serial scanning for a larger part of the display, whereas younger individuals could process a larger area in parallel. When we made the analysis in a linear fashion, such as to emphasize real-world effects, we observed the regular Age × Eccentricity effect.

Acknowledgments

Tanja R. M. Coeckelbergh was supported by Grant 904-65-062 from the Dutch Research Council (NWO). Frans W. Cornelissen was supported by Visio, the Dutch National Foundation for the Visually Impaired and Blind. The authors thank Heleen Ditvoorst, Els Eppink, Monique Boosman, and Daniel Lubbers for their help in carrying out the experiments and Laura Cobb for correcting earlier versions of this manuscript.

Address correspondence to T. R. M. Coeckelbergh, Department of Ophthalmology, University Hospital Gent, De Pintelaan 185, 9000 Gent, Belgium (Tanja.Coeckelbergh@UGent.be) and Department of Ophthalmology, University Hospital Antwerp, Wilrijkstraat 10, 2650 Edegem, Belgium (Tanja.Coeckelbergh@uza.be).

References

Bailey, I. L., & Lovie, J. E. (1976). New design principles for visual acuity letter charts. *American Journal of Optometry and Physiological Optics, 53*, 740–745.

Ball, K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the American Optometric Association, 5*, 2210–2219.

Ball, K., Owsley, C., & Beard, B. (1990). Clinical visual perimetry underestimates peripheral field problems in older adults. *Clinical Vision Sciences, 5*, 113–125.

Birren, J. E., Woods, A. M., & Williams, M. V. (1980). Behavioral slowing with age. In L. W. Poon (Ed.), *Aging in the 1980's* (pp. 293–308). Washington, DC: American Psychological Association.

Carrasco, M., Evert, D. L., Chang, I., & Katz, S. M. (1995). The eccentricity effect: Target eccentricity affects performance on conjunction searches. *Perception and Psychophysics, 57*, 1241–1261.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98*, 67–83.

Cornelissen, F. W., & Kooijman, A. C. (2000). Does age change the distribution of visual attention? A comment on McCalley, Bouwhuis, and Juola (1995). *Journal of Gerontology: Psychological Sciences, 55B*, P187–P190.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). ''Mini-mental state.'' A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Howell, D. C. (1992). *Statistical methods for psychology* (3rd ed.). Belmont, CA: Duxbury Press.

Kaern, C. (1991). Simple adaptive testing with the weighted up-down method. *Perception & Psychophysics, 49*, 227–229.

Kooijman, A. C., Stellingwerf, N., van Schoot, E. A. J., Cornelissen, F. W., & Wildt, G. J. van der (1994). Groningen Edge Contrast Chart (GECKO) and glare measurements. In A. C. Kooijman, P. L. Looijestijn, J. A. Welling, & G. J. van der Wildt (Eds.), *Low vision: Research and new developments in rehabilitation* (pp. 101–110). Amsterdam, The Netherlands: IOS Press.

Kosnik, W., Sekuler, R., & Rasinski, K. (1985, November). *Age-related visual changes and everyday life*. Paper presented at the annual meeting of the Gerontological Society of America, Washington, DC.

McCalley, L. T., Bouwhuis, D. G., & Juola, J. F. (1995). Age changes in the distribution of visual attention. *Journal of Gerontology: Psychological Sciences, 50B*, P316–P331.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.

Salthouse, T. A. (1988). The complexity of age × complexity functions: Comment on Charness and Campbell (1988). *Journal of Experimental Psychology: General, 117*, 425–428.

Scialfa, C. T., Thomas, D. M., & Joffe, K. M. (1994). Age differences in the useful field of view: An eye movement analysis. *Optometry and Vision Science, 71*, 736–742.

Seiple, W., Szlyk J. P., Yang, S., & Holopigian, K. (1996). Age-related functional field losses are not eccentricity dependent. *Vision Research, 36*, 1859–1866.

Sekuler, A. B., Bennett, P. J., & Mamelak, M. (2000). Effect of aging on the useful field of view. *Experimental Aging Research, 26*, 103–120.

Sekuler, R., & Ball, K. (1986). Visual localization: Age and practice. *Journal of the Optical Society of America A, 3*, 864–867.

Sokal, R. R., & Rohlf, F. J. (1995). *Biometry: The principles and practice of statistics in biological research* (3rd ed.). New York: W. H. Freeman.

Watson, A. B., & Pelli, D. G. (1983). Quest: A Bayesian adaptive psychometric method. *Perception and Psychophysics, 3*, 113–120.

Wolfe, J. M., O'Neill, P., & Bennet, S. C. (1998). Why are there eccentricity effects in visual search? Visual and attentional hypotheses. *Perception and Psychophysics, 60*, 140–156.

Received September 11, 2000
Accepted August 12, 2003
Decision Editor: Margie E. Lachman, PhD

Appendix: Log Sensitivity and Linear Threshold Presentation Times

Experiment	Age (years)	Dependent Variable	Eccentricity			
			0°	4°	8°	12°
1	younger	mean log sensitivity	1.88	1.63	0.85	0.40
		SEM log sensitivity	0.01	0.06	0.09	0.06
		mean linear time (ms)	13	32	214	480
		SEM linear time (ms)	0	6	36	48
	older	mean log sensitivity	1.21	0.79	0.23	0.05
		SEM log sensitivity	0.20	0.08	0.07	0.06
		mean linear time (ms)	105	275	731	1100
		SEM linear time (ms)	44	46	108	177
2	older	mean log sensitivity	1.26	0.94	0.67	0.26
		SEM log sensitivity	0.21	0.13	0.08	0.13
		mean linear time (ms)	106	246	325	994
		SEM linear time (ms)	46	106	59	384
			Center	Ellipse 1	Ellipse 2	Ellipse 3
3	31–40	mean log sensitivity	1.43	0.49	0.50	0.34
		SEM log sensitivity	0.24	0.09	0.08	0.07
		mean linear time (ms)	73	443	424	562
		SEM linear time (ms)	36	79	92	71
	41–50	mean log sensitivity	1.16	0.57	0.43	0.19
		SEM log sensitivity	0.16	0.08	0.04	0.04
		mean linear time (ms)	153	462	482	746
		SEM linear time (ms)	64	55	42	51
	51–60	mean log sensitivity	0.95	0.52	0.45	0.29
		SEM log sensitivity	0.16	0.09	0.06	0.06
		mean linear time (ms)	174	510	510	628
		SEM linear time (ms)	59	84	37	69
	61–75	mean log sensitivity	0.34	0.19	0.25	0.05
		SEM log sensitivity	0.22	0.08	0.05	0.05
		mean linear time (ms)	931	948	697	1148
		SEM linear time (ms)	419	192	49	96

Notes: Sensitivity = 1/mean threshold presentation time, in seconds. *SEM* = standard error of the mean.