Chapter 1

Age-related changes in the functional visual field:
further evidence for an inverse age by eccentricity effect.

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Introduction

Older people report difficulties with visual distracters 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 and Ball (1986) citing a study by Kosnik, Sekuler, and 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 distracters 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, i.e. without eye and head movements. Ball and colleagues (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley & Beard, 1990; Sekuler & Ball, 1986) observed that the UFOV was constricted in older adults as compared to that of younger adults.

In this paper, 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 since 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. Subjects are instructed to identify a target presented at various eccentricities and embedded amidst a large number of distracters. Subjects 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 paper 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 to 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 subjects, which has led to the understanding that the UFOV is constricted in older adults (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley & Beard, 1990; Sekuler & Ball, 1986). A graphical representation of this constriction of the field is depicted in Figure 1a. 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 to that in the study by Ball et al. (1988), they observed an eccentricity-independent increase in localization errors as a function of age. Older subjects performed worse than the younger subjects and error rates increased in both age groups as a function of eccentricity. But, 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) compared performance under a divided attention condition (central letter recognition task and a peripheral localization task) as well as a focussed attention condition (only a peripheral localization task) in a younger and an older age group. In the focussed attention condition, the effects of eccentricity, age, and age by eccentricity were significant. In the divided attention condition, however, only the effect of age was significant. There was no increase in errors as a function of eccentricity nor was an age by eccentricity interaction observed. 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. The view of Seiple et al. (1996) and Sekuler et al. (2000) is depicted in Figure 1b. McCalley, Bouwhuis, and Juola (1995) and Cornelissen and Kooijman (2000) have described still another pattern of results. They observed that older subjects have relatively more problems identifying central targets and fewer problems identifying peripheral targets. This interaction is depicted in Figure 1c.

![Schematic representation of the age by eccentricity effect. The X-axis represents the horizontal diameter of the field of view with the center of the field in the middle of the axis. The Y-axis depicts (log) sensitivity. Higher scores indicate better performance.](image)

The present study investigates the effect of age on the functional visual field when using the AFOV paradigm. The effects of age and eccentricity are studied and related to the three schematic representations of Figure 1. The performance of younger and older healthy adults is here investigated as a first step in the standardization of the approach and the development of age-related norms for subjects with visual field defects. It is hypothesized that subjects 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

Method

Subjects

Seven young (range: 22-28 years) and seven older (range: 58-78 years) subjects participated in the first experiment. Subjects 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 females and three males; the older age group consisted of three females and four males. Visual acuity, contrast sensitivity, and visual field measures are reported in Table 1.

Table 1. Mean (and range) of vision parameters in Experiment 1 and Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>young group</th>
<th>older group</th>
<th>older group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>experiment 1</td>
<td>experiment 1</td>
<td>experiment 2</td>
</tr>
<tr>
<td>n=7</td>
<td></td>
<td>n=7</td>
<td>n=7</td>
</tr>
<tr>
<td>visual acuity (decimal notation)</td>
<td>1.3 (0.5-2.0)</td>
<td>1.0 (0.6-2.0)</td>
<td>1.0 (0.6-1.6)</td>
</tr>
<tr>
<td>contrast sensitivity (HFA, dB)</td>
<td>38.70 (36.5-41.5)</td>
<td>33.30 (32.5-35.5)</td>
<td>33.36 (27.5-35.5)</td>
</tr>
<tr>
<td>contrast sensitivity (Gecko, log)</td>
<td>2.05 (1.8-2.15)</td>
<td>1.78 (1.51-2.15)</td>
<td>1.84 (1.68-2.15)</td>
</tr>
</tbody>
</table>

Visual acuity was measured using 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 logMAR in the statistical analyses. Contrast sensitivity was measured using the GECKO (Groningen Edge Contrast Kaart (chart) Ontwerp (design) (Kooijman, Stellingwerf, van Scoot, Cornelissen, & van der Wildt, 1994)) at a distance of 3.8 m. Visual field perimetry was performed using the Central 10-2 and Central 24-2 programs of the Humphrey Field Analyzer (HFA). All tests were carried out binocularly since performance on the AFOV test was also assessed binocularly. Mean visual acuity was within (near-)normal limits for all subjects. The visual acuity of one of the younger subjects was 0.5. When the results on the AFOV were re-analyzed without the scores of this subject, they did not change. It was concluded, therefore, that the lower visual acuity did not affect performance on the AFOV and the subject’s scores were not removed from further analysis.

Apparatus

Stimuli were presented on a 20-inch trinitron monitor controlled by an Apple Macintosh computer. Custom software was written for presenting stimuli using some of the routines from the videotoolbox (Pelli, 1997). Subjects 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 since the pilot study showed that it kept subjects from moving their eyes and head.
Materials
The display consisted of 24 distracters (O) and a single target (a C with its gap oriented in one of four directions: up, down, left or right). The distracters and the target measured 0.5 degrees in diameter. Target gap was 0.1 degree. The stimuli were positioned on a grid along eight radii (oriented at 0, 45, 90, 135, 180, 225, 270, and 315 degrees) and at three eccentricities (4, 8, and 12 degrees). One element was positioned in the center of the display (0 degrees). The display consisted of white stimuli on a gray background (50% contrast). An example of the display is shown in Figure 2.

![AFOV display as used in Experiments 1 and 2. In the actual experiments, white targets were presented on a gray background (50% contrast).](image)

The time that the subjects 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 ran 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 increased, and when the participant made an error the duration was decreased (one-down/one-up rule). The duration never was the same on any two subsequent trials. By using a weighted up-down method (i.e. having a larger increase during errors than (absolute) decrease during correct responses the staircase converges on the 67% correct point (delta-/delta+ ratio of 1:2, Kaernbach 1991).

Initial presentation time for the first trial was 1 second. To adapt this initial presentation time to the performance of the subject, a separate and independent procedure (Quest, 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 two were ignored. Next, error and correct response related reversals were sorted and averaged separately, after having removed the highest and lowest value from each set. The final value is the average of the mean error and correct response reversals (and was thus based on 6 reversals). Removing the highest and lowest values is done 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 from e.g. 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 subjects at the same criterion level of performance so that the results were not affected by different subjects making different speed/accuracy trade-offs. Measuring threshold presentation times also eliminated the confounding effect of differences in motor response time since the response mode was not reaction time-based. Subjects responded by indicating the direction of the gap. Reaction times of the responses were not monitored.

Analogous to contrast sensitivity, the results in this paper are (mainly) reported in terms of sensitivity, which we define as \( 1/(\text{presentation time in seconds required to correctly locate and identify the target}) \).

The data were log-transformed for statistical reasons (normal distribution and homogeneity of variances) and to account for a general slowing in the older age group (see Cornelissen & Kooijman (2000) for a discussion).

**Procedure**

A central fixation point was shown before the presentation of the display. Subjects 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. Subjects 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 distracters was always identical to the presentation time of the target. The test was performed binocularly and the subjects 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.

**Statistical analysis**

Only the 4, 8, and 12 degrees eccentricity data were included in the statistical analysis. This was done for two reasons. First, there was only a single measurement for 0 degrees eccentricity compared to eight for the other three eccentricities, which made it difficult to include this value into the repeated measures ANOVA. Second, younger subjects 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 subjects.

**Results**

*Functional Visual Field*

Figure 3 plots the log sensitivity (= 1/presentation time) of the older and younger subjects as a function of eccentricity. Mean log sensitivity, standard error of the mean, and linear threshold presentation times are presented in Table 2 (small stimulus size).

Older subjects required on average about 4 times (~0.6 log units) longer presentation times than younger subjects to correctly locate and recognize the target (older subjects: 0.36 log sensitivity (= 437 ms) versus younger subjects: 0.96 log sensitivity (= 109 ms)). 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 subjects 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 can be seen in Figure 3, the decline in sensitivity with eccentricity was larger for the younger than for the older subjects. The difference between the younger and the older subjects was about a factor of 7 (~0.8 log units) at 4 degrees eccentricity, but only a factor of 2 (~0.35 log units) for targets at 12 degrees eccentricity. Although not included in the analysis, the 0 degree data were in line with this finding.
Table 1 shows that, although within normal limits, contrast sensitivity as assessed with the HFA ($F(1,12)=54.20$, $p<.001$) and GECKO ($F(1,12)=6.61$, $p<.05$) of older subjects was significantly reduced as compared to that of the younger subjects. Visual acuity was also lower, but this effect was not significant ($F(1,12)=1.34$, n.s.).

Vision

Table 2. Log sensitivity and linear threshold presentation times (Experiment 1 and Experiment 2)

<table>
<thead>
<tr>
<th>age group</th>
<th>stimulus size</th>
<th>eccentricity</th>
<th>mean log sensitivity</th>
<th>S.E.M. (log sensitivity)</th>
<th>mean linear time (ms)</th>
<th>range linear time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>younger</td>
<td>small</td>
<td>$0^\circ$</td>
<td>1.88</td>
<td>0.01</td>
<td>13</td>
<td>13-14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4^\circ$</td>
<td>1.63</td>
<td>0.06</td>
<td>24</td>
<td>20-27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8^\circ$</td>
<td>0.85</td>
<td>0.09</td>
<td>140</td>
<td>114-172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$12^\circ$</td>
<td>0.40</td>
<td>0.06</td>
<td>395</td>
<td>344-454</td>
</tr>
<tr>
<td>older</td>
<td>small</td>
<td>$0^\circ$</td>
<td>1.21</td>
<td>0.20</td>
<td>61</td>
<td>39-96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4^\circ$</td>
<td>0.94</td>
<td>0.08</td>
<td>161</td>
<td>39-96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8^\circ$</td>
<td>0.67</td>
<td>0.07</td>
<td>588</td>
<td>497-693</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$12^\circ$</td>
<td>0.26</td>
<td>0.06</td>
<td>885</td>
<td>764-1025</td>
</tr>
<tr>
<td>older</td>
<td>large</td>
<td>$0^\circ$</td>
<td>1.26</td>
<td>0.21</td>
<td>55</td>
<td>34-90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4^\circ$</td>
<td>0.94</td>
<td>0.13</td>
<td>116</td>
<td>86-156</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8^\circ$</td>
<td>0.67</td>
<td>0.08</td>
<td>214</td>
<td>178-258</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$12^\circ$</td>
<td>0.26</td>
<td>0.13</td>
<td>553</td>
<td>214-454</td>
</tr>
</tbody>
</table>

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1 small stimulus size = $0.5^\circ$ ($0.1^\circ$ gap); large stimulus size = $1.0^\circ$ ($0.2^\circ$ gap)
2 sensitivity = 1/mean threshold presentation time in seconds
3 linear time = linear threshold presentation time (reconverted from log values)

Vision

Table 2 shows that, although within normal limits, contrast sensitivity as assessed with the HFA ($F(1,12)=54.20$, $p<.001$) and GECKO ($F(1,12)=6.61$, $p<.05$) of older subjects was significantly reduced as compared to that of the younger subjects. Visual acuity was also lower, but this effect was not significant ($F(1,12)=1.34$, n.s.).

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 4 as a function of age and eccentricity. It can be seen that the threshold presentation times for older subjects are disproportionately high in the periphery. These results corroborate previous findings of a constricted UFOV in older adults. The area that older subjects could process at 100 ms, for example, was much smaller than that processed by younger adults. In fact, the UFOV of younger subjects extended to almost six degrees when they could view the field for 100 ms while older subjects could only process the central stimulus in this brief amount of time.
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 to the stimulus durations used in studies on the UFOV and precludes eye movements.

![Graph showing linear threshold presentation times as a function of eccentricity and age.](image)

**Figure 4.** 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 to the stimulus durations used in studies on the UFOV and precludes eye movements.

### Experiment 2: Test of foveal performance in the older group

The reduced contrast sensitivity and the slightly lower visual acuity of the older group indicates that vision was not equivalent in the two age groups. Moreover, the lower visual performance of older subjects 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.

### Method

**Subjects**

Seven older subjects (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 females and five males. 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 the distracters was increased to 1.0 degree and gap size was increased to 0.2 degree.

**Results**

The results of Experiments 1 and 2 are plotted in Figure 3. Mean log sensitivity, standard error of the mean, and linear threshold presentation times are presented in Table 2. The data of older subjects with large stimuli were compared to those of younger subjects with small stimuli from Experiment 1. Log sensitivity for large targets was higher than log sensitivity for small targets ($F(1,12)=4.64; p=0.05$), 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 by 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. 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.

**Method**

**Subjects**

Thirty-four volunteers participated in this experiment. They were recruited by an advertisement in a local papers. Nineteen men and 15 women participated in this experiment. All subjects scores well above a predefined cut-off score on a cognitive screening test (MMSE, Folstein et al., 1975). Scores ranged between 23 and 29. Subjects were allocated to one of four age groups: group 1, 31 to 40 years of age ($n=6, \text{M}=35 \text{ years, SD}=4 \text{ years}$); group 2, 41 to 50 years of age ($n=13, \text{M}=45 \text{ years, SD}=3 \text{ years}$); group 3, 51 to 60 years of age ($n=8, \text{M}=53 \text{ years, SD}=2 \text{ years}$), and group 4, older than 60 years of age ($n=7, \text{M}=68 \text{ years, SD}=4 \text{ years}$). None of the subjects had participated in Experiments 1 and 2. All subjects reported good ocular health. Visual acuity (Bailey-Lovie chart, mean=1.1, SD=0.3) or a near visual acuity were tested. In the near visual acuity test, the minimal size of the target gap was determined for each subject 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 subjects.

**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 degrees horizontally and 24 degrees 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 5a. 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 (Figure 5b).

**Figure 5.** Figure 5a depicts an example of the AFOV stimulus as presented to the subjects in Experiment 3. In the actual experiment, white targets were displayed on a gray background (50% contrast). Six positions per ring were analyzed (Figure 5b): some positions were pooled and analyzed as one position. The pooled positions are connected with a gray line in Figure 5b. The subject 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 subject responded correctly in 67% of the trials. Presentation time varied from 8 ms to 10 s.

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 subjects in Experiment 1. Target size was 1.4 degrees for the center target and first ellipse, 1.9 degrees for the second ellipse, and 2.4 degrees for the outer ellipse. The stimuli were presented with varying presentation times (range: 8 ms - 10 s). Using a staircase procedure, the presentation time at which the subject could correctly identify the target in 67% of the trials was determined for each of the 19 positions.
**Procedure**

The subject 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 analyzed using a General Linear Model (GLM) repeated measures procedure on the log sensitivity data (= 1/presentation time) with position of the target (center, ellipse1, ellipse2, and ellipse3) 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 6. Mean log sensitivity, standard error of the mean, and linear threshold presentation times are presented in Table 3.

![Figure 6](image)

*Figure 6. Log sensitivity (=1/threshold presentation time) data on the scaled AFOV test as a function of ellipse (eccentricity) and age. The inverse age by 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.*

The results indicated that older subjects needed longer presentation times to detect the target than younger subjects ($F(3,30)=8.15$, $p<.01$). Post hoc analysis (Bonferroni multiple comparisons) indicated
that the oldest group (> 60 years of age) differed significantly from the other age groups \( (p < .05) \), while 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 by position interaction: \( F(4.5, 44.8)=2.65, \ p < .05) \). Visual inspection of Figure 6 indicates that the eccentricity effect was larger for the three younger groups than for the oldest group.

**Table 3. Log sensitivity and linear threshold presentation times (Experiment 3)**

<table>
<thead>
<tr>
<th>age group</th>
<th>position</th>
<th>center</th>
<th>ellipse1</th>
<th>ellipse2</th>
<th>ellipse3</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-40 y</td>
<td>mean log sensitivity(^1)</td>
<td>1.43</td>
<td>0.49</td>
<td>0.50</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>S.E.M. (log sensitivity)</td>
<td>0.24</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>mean linear time(^2) (ms)</td>
<td>37</td>
<td>324</td>
<td>314</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>range linear time (ms)</td>
<td>21-64</td>
<td>263-399</td>
<td>260-379</td>
<td>390-542</td>
</tr>
<tr>
<td>41-50 y</td>
<td>mean log sensitivity</td>
<td>1.16</td>
<td>0.57</td>
<td>0.43</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>S.E.M. (log sensitivity)</td>
<td>0.16</td>
<td>0.08</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>mean linear time (ms)</td>
<td>70</td>
<td>269</td>
<td>373</td>
<td>641</td>
</tr>
<tr>
<td></td>
<td>range linear time (ms)</td>
<td>48-101</td>
<td>223-325</td>
<td>341-409</td>
<td>592-695</td>
</tr>
<tr>
<td>51-60 y</td>
<td>mean log sensitivity</td>
<td>0.95</td>
<td>0.52</td>
<td>0.45</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>S.E.M. (log sensitivity)</td>
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<td>0.09</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>mean linear time (ms)</td>
<td>113</td>
<td>299</td>
<td>359</td>
<td>516</td>
</tr>
<tr>
<td></td>
<td>range linear time (ms)</td>
<td>78-164</td>
<td>245-365</td>
<td>315-409</td>
<td>453-588</td>
</tr>
<tr>
<td>61-75 y</td>
<td>mean log sensitivity</td>
<td>0.34</td>
<td>0.19</td>
<td>0.25</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>S.E.M. (log sensitivity)</td>
<td>0.22</td>
<td>0.08</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>mean linear time (ms)</td>
<td>461</td>
<td>640</td>
<td>569</td>
<td>887</td>
</tr>
<tr>
<td></td>
<td>range linear time (ms)</td>
<td>280-760</td>
<td>527-775</td>
<td>513-637</td>
<td>788-997</td>
</tr>
</tbody>
</table>

\( ^1 \) sensitivity = 1/mean threshold presentation time in seconds

\( ^2 \) linear time = linear threshold presentation time (reconverted from log values)

**Discussion**

The present study investigated age-related effects on a visual search task under free-viewing conditions. The Attended Field of View (AFOV) test was introduced to assess the time needed to identify targets in different positions of the field when eye movements were allowed. Differences between the age groups with regard to manual motor responses and general slowing were excluded
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 subjects needed longer presentation times to detect the target than younger subjects. All subjects 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 by eccentricity effect since 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 subjects in the second experiment. This manipulation did not affect older subjects’ 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 3). 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 by eccentricity interaction remained (Figure 6).

An inverse age by eccentricity interaction was first reported by Cornelissen and Kooijman (2000) in their comment on the study by McCalley and colleagues (1995) and is schematically shown in Figure 1c. McCalley et al. (1995) reported that older subjects performed inferiorly in the central area when no positional cue was present. Their hypothesis was that subjects 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 due, for instance, to a decreased foveal sensitivity. The strategy to concentrate on extracentral space might have been used by the older subjects 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 acuity threshold level (Experiment 2). Other visual factors might also be involved. Crowding, for instance, might have played a role since 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 subjects are less affected by eccentricity than younger subjects is not in accordance with some previous conclusions. Ball and colleagues (Ball et al., 1988, 1990) reported an increasing difference between age groups with increasing eccentricity (Figure 1a). Seiple et al. (1996) and Sekuler et al. (2000) reported an almost equivalent difference between the age groups at all eccentricities (Figure 1b). 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 abovementioned studies is the logarithmic transformation. Our data were log-transformed for two reasons. Firstly, ANOVA requires that data are normally distributed and that the variances in both samples are equivalent. This was clearly not the case in our linear data since the standard deviations increased as a function of the mean threshold presentation times (see Figure 4). Log-transforming the data resolved both problems. Secondly, a general slowing of the older population had to be ruled out as the cause of the age-related differences. The effects of general slowing and eccentricity had to be unraveled. 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. Data on a linear scale may lead to the erroneous conclusion of a large eccentricity effect in the older age group. Log-transforming the data removes the effect of general slowing, leaving only the effect of eccentricity.

The log transformed data showed that the eccentricity effect was larger for young subjects than for older subjects. This effect is largely caused by age-related differences in sensitivity to centrally located targets. In Experiment 1, older subjects needed 61 ms to detect the central target whereas younger subjects 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 subjects needed longer threshold presentation times than young subjects for the central target. It seems unlikely that decreased foveal resolution has caused this effect as it remained when stimuli were enlarged (Table 2). As reported before, other factors such as attention to an extracentral space by older subjects (McCalley et al., 1995) or crowding might have played a role.

The inverse age by eccentricity effect might further be explained by different search strategies of the age groups. Linear data showed that the area that older subjects could process at presentation times of 100 ms (equivalent to presentation times used in many UFOV studies) was smaller than that of younger subjects. Older subjects could only process the central stimulus when eye movements were precluded whereas younger subjects could process up to almost six degrees. We deduced from this finding that the UFOV of older subjects is smaller than that of younger subjects. Older subjects 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 subjects 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. Yet, we observed a much smaller age-related difference for peripheral targets than for central targets. These data suggest, therefore, that older subjects’ serial scanning ability remained intact.

As we did not measure the subjects’ eye movements, we cannot be sure about the specific strategy the subjects used nor about the differences between older and younger subjects in their use of eye movements. Scialfa, Thomas, and Joffe (1994) showed in their experiments that older subjects made
two to three times as many saccades during search as younger subjects. 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 et al. (1995). Due to the short presentation time used in study of McCalley et al. (1995), no eye movements could be made and, therefore, eye movements could not be at the basis of the inverse age by eccentricity effect in this study. Clearly, more investigation is needed on the effect of age on eye movement behavior while performing visual search tasks.

**Backward masking screen**

We did not use a backward masking screen. Seiple et al. (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, since Seiple et al. (1996) did not report an interaction effect with age, it remains unclear why the diminished eccentricity effect was observed for just the older subjects.

**Dual task**

Studies often report results of divided attention conditions in which subjects 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 et al. (1988, 1990) reported that the presence of a central task had a greater effect on the localization scores of older subjects and that the difference between the age groups increased as a function of eccentricity. Since the effect of the concurrent central task was most evident for the older subjects 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 et al. (2000), who observed an age by 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, while 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 subjects 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 et al. (1995) reported that the (linear) age by target location effect disappeared when the stimuli were scaled. However, as noted by Cornelissen and Kooijman (2000), the results of McCalley et al. suggested an overcompensation for eccentricity and when logarithmically analyzed, the inverse age by 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 subjects were allowed to make eye movements. When analyzed in a logarithmic fashion in order to eliminate the influence of general slowing, we consistently found an "inverse" age by eccentricity effect. That is, eccentricity had a smaller effect on older subjects' performance than on younger subjects' 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 subjects processed a smaller field of view than younger subjects. Consequently, older subjects were forced to resort to serial scanning for a larger part of the display whereas younger subjects could process a larger area in parallel. When analyzed in a linear fashion, such as to emphasize "real-world" effects, we observed the "regular" age by eccentricity effect.

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