Aging, Texture Segmentation, and Exposure Duration: Evidence for a Deficit Is Preattentive Processing

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Younger and older observers were asked to detect the presence and identify the orientation of an orientation-based texture target presented at durations ranging from 15 to 75 ms. In Experiment 1a, an age by duration interaction indicated that older adults were less able to process the displays at short durations. In Experiment 1b, a group of younger adults was given the task under conditions designed to simulate age-related changes in retinal illuminance. Their performance was independent of luminance, and was still superior to that of older adults in Experiment 1a. Several mechanisms are potential contributors to these age deficits in lower-level processing that can influence higher-level visual perception.

In a typical texture segmentation task, a small region of uniform orientation is segregated from a surrounding region of a different orientation. The texture target is preattentively detected when the featural gradient between the two regions is sufficiently large (Julesz, 1986; Northdurft, 1985a, 1985b, 1991, 1992). However, identification of the features in the texture target takes more time and effort. The purpose of the present experiments was to determine if older adults and younger adults demonstrate the same time course for detection and identification in a texture-segmentation task.

It is thought that segmentation is based on the detection of a generalized difference between the two regions of the display (Nothdurft, 1999).
A generalized difference operator is sensitive to texture gradient (e.g., a local orientation difference) but not to specific features comprising that difference. Such a mechanism is found in computational models of texture segmentation (Landy & Bergen, 1991; Malik & Perona, 1990), as well as the bottom-up component of the Guided Search Model (Cave & Wolfe, 1989; Wolfe, 1994). A differencing operator was invoked by Atkinson and Braddick (1989) to account for the finding that target localization in feature search occurs more rapidly than does target identification. They argued that coarse localization is based on the detection of “feature gradients” that can “signal where without knowing what the target is, except that it is different” (Atkinson & Braddick, 1989, p. 182). Sagi and Julesz (1985a, 1985b) also found that localization and detection of multiple feature targets occurred more quickly than did discrimination among the targets. This would occur if specific feature values (i.e., “what”) became available only after a featurally undifferentiated object had been detected and crudely localized.

In a direct test of these assertions, Scialfa and Joffe (1995, Experiment 5) presented young adults with a texture-segmentation task at display durations ranging from 14 to 70 ms. The observers were asked to detect the presence of a texture patch and then discern its orientation. Detection accuracy exceeded identification accuracy at all durations, but these differences were minimized as duration increased. This pattern would be expected if the output of a generalized difference operator was available more quickly than the specific orientation feature values.

Will older adults exhibit any deficits in a texture-segmentation task? On the one hand, studies from the domain of visual search would suggest not. There are only small age deficits in orientation feature search (Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989; Scialfa, Thomas, & Joffe, 1994; Scialfa & Joffe, 1997; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000), at least when orientation differences are large (Scialfa, Esau, & Joffe, 1998). Although effortless texture segmentation and parallel visual search are not identical (Wolfe, 1994), to the extent that the preattentive processes mediating feature search are those involved in texture segmentation, one would expect few age differences in the latter.

On the other hand, texture gradients must be sufficiently steep to support segmentation, and we do not know if threshold gradients are constant across the life span. Some data from visual search tasks suggests that this might not be the case. Scialfa et al. (1994) found that older adults had more difficulty than the young in detecting orientation-based targets when they were embedded in heterogenous distractors that diminished the texture gradient. Furthermore, Scialfa et al. (1998) observed that age differences in display size effects in feature and conjunction search were greater when the texture gradient was diminished.
In a related study, Scialfa and Harpur (1994) presented younger and older observers with feature-search displays wherein target-distractor orientation differences were set at 30, 50, or 90 deg. Exposure duration varied from 50 to 400 ms. At the longest duration, younger adults’ target-absent accuracy was at ceiling in all similarity conditions. For older adults, there was still a 7% drop in mean accuracy between the low- and high-similarity conditions, indicating that they might need more time to process featurally confusable displays. As well, Harpur, Scialfa, and Thomas (1995) presented younger and older people with limited-duration feature-search displays involving response-compatible and -incompatible distractors. Older adults were particularly disadvantaged at short durations and, on response-incompatible trials, required more than 1600 ms before they reached the accuracy level of the young. Thus, in several studies, age differences in detecting orientation-based targets increased with either diminished texture gradients, decreased exposure duration, or both. This would be expected if a generalized difference operator was subject to diminished sensitivity in old age.

The present study was modeled after Scialfa and Joffe’s (1995) Experiment 5. Observers were presented with texture displays at durations ranging from 15 to 75 ms. They were asked to either detect the presence of a texture target or identify the orientation of elements within that target. We expected that detection accuracy would exceed identification accuracy at short durations but, as suggested by the preceding discussion, it was not clear that age differences in performance, either on average or in interaction with duration, were to be anticipated.

**EXPERIMENT 1a**

**Method**

**Participants**

Ten younger and an equal number of older observers took part in this experiment. The young group consisted of four men and six women who had an average age of 22 years (range = 17–28 years). The older group was composed of three men and seven women who had an average age of 63 years (range = 54–69 years). The younger group had a mean education level of 16 years (range = 13–20 years and the older group had a mean education level of 15.2 years (range = 12–20 years). These differences were nonsignificant. All participants were community-dwelling, reported themselves to be in good general and ocular health, and were not currently seeing a physician for a “serious medical condition.” None
had previous experience with texture-segmentation tasks. Each participant was paid $10 (CDN) for their contribution, which lasted approximately 1 hr.

Everyone was refracted at the test distance of 45 cm and had a corrected visual acuity of 20/30 or better. After correction, although acuity was better in the younger observers \( (p = .096, \text{ two-tailed}) \), both groups averaged better than 20/20 vision at the test distance. Intraocular pressure was assessed to guard against the possibility of undetected glaucoma and associated declines in peripheral sensitivity. There were no age differences in intraocular pressure \( (p > .50) \), which was within the normal range (12–19 mm Hg) for all observers.

**Materials and Apparatus**

Each trial consisted of a three-screen sequence of a fixation stimulus, texture display, and masking display. The first of these, the fixation stimulus, was composed of five black circles. Four of the circles, each .25 deg in diameter, were placed at the corners of an imaginary square subtending 1.02 deg on a side. A fifth circle, .382 deg in diameter, was centered in this configuration.

The texture displays were based on those of Scialfa and Joffe (1995). They were composed of 336 vertically oriented lines, .76 deg in length and .13 deg in width. The minimum and maximum separation between lines was .13 and .64 deg, respectively. To create the texture target, in each display nine of the vertical lines were replaced with a 3 × 3 matrix of lines oriented either 45 deg left or 45 deg right of vertical, and arranged within an imaginary square subtending 2.16 deg per side. This target square was randomly positioned at one of two locations corresponding to 7 deg above or below fixation. Thus, there were four texture displays resulting from the combination of two target orientations and two target locations.

Masking stimuli contained 336 elements, each composed of three bisecting lines oriented at 45, 90, and 135 deg. These elements were placed in the same positions occupied by the elements in the previous texture displays.

All items were presented on an white background with a luminance of 81.88 cd/m². Michelson contrast for the black vertical lines items was 80.6%.

Stimuli were generated and data collected using VScope 1.2b (Rensink & Enns, 1993) on a Macintosh IIsi (Apple Computer, Inc., Cupertino, CA) with a 53-cm high-resolution monitor (frame rate = 66 Hz) set to black and white. Viewing distance was maintained and gaze angle was held at approximately 0 deg using an adjustable chin rest. Optical corrections were provided with a Bausch & Lomb 100 TLS trial lens set and Burton frames. Responses were made manually by using the “arrow” keys on a standard keyboard.
**Procedure**

Observers performed the task binocularly. In order to control for any discomfort associated with the trial frames, if no correction was required, the frames were worn without corrective lenses.

Each observer-initiated trial began with the presentation of 1000-ms fixation stimulus, followed by a 675-ms blank screen. The texture display was then presented for a duration of 15, 30, 45, 60, or 75 ms and was followed immediately by a 1000-ms mask.

There were two departures from the procedure used by Scialfa and Joffe (1995, Experiment 5). In that study, observers made a present-absent decision for detection but a two-alternative, forced choice (2AFC) regarding orientation of the elements within the target. This may have allowed differences in criterion setting to influence the former but not the latter. In order to avoid this possibility, which may interact with age, we created a two-alternative, forced-choice version of both tasks. That is, each participant was required either to indicate whether the target was above or below the fixation stimulus, or whether the orientation of the target was left or right.

Second, in Scialfa and Joffe (1995), observers were required to first detect target presence and then, within the same trial, report target orientation. This procedure confounds the tasks with memory demands that are also age-sensitive (Wingfield, Lahar, & Stine, 1989). To avoid these potential problems, one half of the observers performed the orientation-identification task first, while the others first performed the detection task. They were completed on two separate dates, separated by no more than 48 hr. Each person completed 64 trials for each of the five test durations, which were presented in separate blocks. Duration order, target orientation, and target location were randomized.

**Results**

Average accuracy is shown in Table 1, where it can be seen that both young and older observers were more accurate at detecting the target than identifying it. In addition, older adults were generally less accurate than their younger counterparts, but these differences depended on the duration for which the displays were exposed.

A split-plot analysis of variance (ANOVA) with age as the only between-subject factor confirmed these trends. The main effect of task was significant \((F(1, 18) = 13.44, p = .002, \text{partial } \eta^2 = .441)\), as were the main effects of age \((F(1, 18) = 10.70, p = .004, \text{partial } \eta^2 = .386)\) and display duration \((F(4, 68) = 69.38, p < .001, \text{partial } \eta^2 = .803)\). Neither the age by task \((F(1, 18) = 2.47, p = .135, \text{partial } \eta^2 = .127)\), the task by duration \((F(4, 68) = 1.58, p = .214, \text{partial } \eta^2 = .085)\), nor the age by task by duration effects were significant \((F(4, 68) = .71, p = .41, \text{partial}...
TABLE 1 Experiment 1a. Average Accuracy (Standard Errors) as a Function of Age, Exposure Duration, and Task

<table>
<thead>
<tr>
<th>Display duration (ms)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target detection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young adults</td>
<td>60.80</td>
<td>85.30</td>
<td>95.20</td>
<td>98.20</td>
<td>99.00</td>
</tr>
<tr>
<td></td>
<td>(0.79)</td>
<td>(1.38)</td>
<td>(0.56)</td>
<td>(0.15)</td>
<td>(0.18)</td>
</tr>
<tr>
<td>Old adults</td>
<td>50.22</td>
<td>61.00</td>
<td>76.44</td>
<td>89.44</td>
<td>93.22</td>
</tr>
<tr>
<td></td>
<td>(0.43)</td>
<td>(1.80)</td>
<td>(2.33)</td>
<td>(1.79)</td>
<td>(1.31)</td>
</tr>
<tr>
<td>Target identification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young adults</td>
<td>48.60</td>
<td>67.90</td>
<td>90.60</td>
<td>94.10</td>
<td>95.10</td>
</tr>
<tr>
<td></td>
<td>(0.84)</td>
<td>(1.80)</td>
<td>(1.56)</td>
<td>(1.40)</td>
<td>(1.27)</td>
</tr>
<tr>
<td>Old adults</td>
<td>47.78</td>
<td>54.33</td>
<td>68.33</td>
<td>90.00</td>
<td>93.00</td>
</tr>
<tr>
<td></td>
<td>(1.22)</td>
<td>(0.95)</td>
<td>(2.80)</td>
<td>(1.34)</td>
<td>(1.84)</td>
</tr>
</tbody>
</table>

$\eta^2 = .04$). The only higher-order effect was a significant display duration by age interaction ($F(4, 68) = 3.27$, $p = .032$, partial $\eta^2 = .161$), which is depicted in Figure 1. At 15, 60, and 75 ms, there were small age differences in performance. At 30 and 45 ms, younger adults were more accurate than the elderly.

Follow-up, pairwise comparisons corroborated these trends. The average accuracy of younger and older observers differed significantly at display durations of 30 ms ($F(1, 18) = 11.58$, $p = .003$) and 45 ms ($F(1, 18) = 8.09$, $p = .011$). No other differences were significant.

Discussion

As expected, the performance of younger and older observers improved with exposure duration. Furthermore, all observers were better at detecting the texture region than they were at discerning the orientation of the discontinuity. This latter finding is consistent with the view that segmentation relies on detection of local differences in simple features such as orientation (Landy & Bergen, 1991; Malik & Perona, 1990) and that information regarding local texture gradients is available before the feature values comprising the gradients can be identified (Atkinson & Braddick, 1989; Scialfa & Joffe, 1995).

Comparing performance of younger individuals in this experiment to Scialfa and Joffe’s Experiment 5 (1995; see their Figure 2), the major difference lies in the short-duration identification data. In the earlier study, identification accuracy averaged under 40% at 14, 21, and 28 ms. In the current data, identification accuracy was consistently above 50%. Across-study differences in detection accuracy were considerably smaller.
FIGURE 1 Experiment 1a. Average accuracy as a function of age and exposure duration.

For example, Scialfa and Joffe report that average detection accuracy was approximately 66% in the 14-ms duration condition, whereas younger observers averaged 61% detection accuracy at 15 ms here.

There are two likely explanations of these apparent discrepancies. First, we have adopted a criterion-free procedure for both detection and identification in the present study, removing the possibility that identification accuracy might be reduced because of a conservative bias. Second, we have circumvented the confound of task and memory demands by asking observers to perform detection and identification tasks singly and in counterbalanced order. It appears that one or both of these procedural changes were successful. As a consequence, the differences between detection and identification were reduced relative to earlier work, but still indicate that detection of local differences is the easier task.

Older adults performed at a level that was generally lower than that of the young, but the age by duration interaction complicates this trend. At the shortest exposure duration, both age groups had a difficult time processing the displays. At intermediate durations, the younger adults detected the texture gradients and identified their orientation significantly more accurately than the elderly. At the relatively longer exposure durations the elderly “caught up” as everyone approached the ceiling.

The age deficits in identification were to be expected. Madden and Allen (1991) have found that older observers require more time to extract
simple features, and Harpur et al. (1995) showed that this puts the elderly at disadvantage in limited-duration, orientation-dependent tasks. Predictions regarding age differences in detection were less straightforward. To the extent that this is a preattentive task or one requiring minimal amounts of selective attention, the feature search literature (Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989) provides some suggestion for age constancy in performance. Furthermore, although it is not known if orientation sensitivity per se declines in old age, under the constraints of the 2AFC procedure, local orientation differences were near maximum and greatly exceeded the orientation thresholds in the young (Deubel, Findlay, Jacobs, & Brogan, 1988), and so this is an unlikely explanation of the age deficits observed.

The fact that age differences were found at intermediate durations in both detection and identification suggests that the explanation involves a mechanism or property common to both tasks, and one of the more obvious candidates is retinal illuminance. Pupillary miosis and opacification of the lens significantly reduce illumination on the retina of the older eye (Weale, 1961) and this may impact preattentive tasks. Beck, Graham, and Sutter (1991) observed that texture segmentation can be disrupted at low and high background luminance, but Beck (1994) showed that it was element-interspace luminance ratios and not background luminance that most strongly affected perceived segregation. In all of these cases, as well, the task involved element-arrangement patterns that have different luminance distributions, and so may not generalize to our orientation-defined textures. Thus, although age-related declines in retinal illumination may impact preattentive tasks, it is not clear that the impact would be manifested in orientation-based segmentation. This provided the motivation for the following control experiment.

**EXPERIMENT 1b**

Older adults showed deficits in Experiment 1a in intermediate-duration detection and identification performance. If these deficits were due to age-related declines in retinal illuminance, then we would expect younger adults to show similar declines in performance when under reduced retinal illumination conditions. Given the limited luminance range of most computer monitors including our own, using neutral density filters to reduce retinal illuminance in younger adults is more feasible than increasing retinal illuminance in the elderly.

**Method**

Five young observers with corrected visual acuity of 20/30 or better and normal intraocular pressure took part in this experiment. Their
average age was 27.8 years (range = 24–38 years), and they had a mean education level of 17.6 years (range = 17–19 years). None of the observers had previous experience with texture segmentation tasks. All volunteers were compensated $10 (CDN) for their participation, which lasted approximately 1 hr.

Stimuli and procedures were identical to Experiment 1a but for the following: Participants were required to wear the trial lenses fitted with Kodak Wratten neutral density filters. These filters reduced stimulus luminance to approximately 17% of that used in Experiment 1a. As in Experiment 1b, the black texture elements (2.14 cd/m²) were presented on a light background (13.86 cd/m²), so that Michelson contrast for the black vertical lines items was 73.30%.

Results

Average accuracy data are presented as a function of task, duration, and illumination condition in Table 2, where several trends can be discerned. As in Experiment 1a, detection was consistently easier than identification and performance improved monotonically with exposure duration. However, reduced illumination did not result in poorer accuracy in either the detection or identification conditions. In fact, in most conditions, reduced illumination produced small benefits for accuracy. These results were confirmed in a Task (2) × Illumination (2) × Display Duration (5) ANOVA, wherein the only significant effect was that of time ($p < .001$).

To facilitate an integration of the data from Experiments 1a and 1b, comparable data are plotted in Figure 2. Here it can be seen that

<table>
<thead>
<tr>
<th>Target detection</th>
<th>Display duration (ms)</th>
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<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Normal illumination</td>
<td>52.22</td>
</tr>
<tr>
<td>Reduced illumination</td>
<td>60.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target identification</th>
<th>Display duration (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Normal illumination</td>
<td>45.32</td>
</tr>
<tr>
<td>Reduced illumination</td>
<td>50.94</td>
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</table>
reduced retinal illuminance produces small and positive effects in young adults. As might be expected, it can also be seen that older adults’ relative disadvantage at durations of 30 and 45 ms is not the result of a naturally occurring reduction in retinal illuminance.

GENERAL DISCUSSION

The present data allow us to draw several conclusions regarding texture segmentation and aging. Older adults had difficulty detecting local, orientation-based discontinuities that are believed to be responsible for preattentive segmentation of displays. In equal magnitude the elderly exhibited deficits in extracting featural information from the same time-limited displays. Given the protocol that assessed detection and identification as single tasks without criterion-based confounds, the age deficits obtained are not due to differences in decision bias, memory demands, or output interference. Because of the large orientation difference defining the display discontinuities, neither is it likely that the results obtained are the result of age differences in orientation thresholds. Experiment 1b indicates that the differences are not the result of age-related changes in retinal illumination. Nothdurft (1993) has reported that orientation-based segmentation is not related to image blur, so the small age differences in acuity are not problematic either. Having eliminated a few causal hypotheses, we can now point to potential explanatory processes that will form the basis of future work.

One possibility is that the spatial scale of the displays was not sufficient to support rapid segmentation in the older observers. Joffe and
Scialfa (1995, Experiment 2) found that texture segmentation varies as a function of both the size of the discontinuity defining the “target” and the size/spacing of the individual elements. Gray and Regan (1998) reported that decreases in line length (i.e., roughly, increases in spatial frequency) produce deteriorations in spatial frequency discrimination for gratings defined by orientation texture. Given that age-related changes in spatial vision produce the greatest decrements at intermediate and higher spatial frequencies (Owsley, Sekuler, & Siemsen, 1983; Scialfa, Adams, & Giovanetto, 1991), it is possible that the “grain” of our displays put the elderly at a disadvantage. A logical next step would be to examine age differences in the speed of segmentation while varying the spatial frequency of the displays across a range that covers the human contrast sensitivity function.

The second possibility is that age differences in performance reflect diminished peripheral function that has been observed in clinically measured visual fields and the useful field of view (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Scialfa, Kline, & Lyman, 1987). Texture segmentation depends on retinal location (Gurnsey, Pearson, & Day, 1996; Kehrer, 1987, 1989; Meineke, 1989; Pearson & Gurnsey, 1992; Joffe & Scialfa, 1995) and we chose our displays because for young adults in the intermediate spatial-frequency range, segmentation is best in the near periphery. It is possible, however, that the optimal eccentricity for an elder observer is generally more central than is the case in younger people.

Whatever the explanation, age differences in orientation-based texture segmentation have implications for visual processing that are not insubstantial. Segmentation supports several aspects of visual perception including localization, figure-ground relations, depth perception, and the execution of voluntary eye movements. As such, age deficits in segregation, if robust across variation in stimuli, can impact several visually guided behaviors and future research will necessarily be directed at understanding both their scope and explanation.

REFERENCES


Texture Segmentation


