Ocular Contributions to Age-Related Loss in Coarse Stereopsis

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ABSTRACT: Purpose: To determine the basis for the dramatic decline in coarse stereopsis that occurs with age. Methods: The Frisby test was used to assess stereopsis in a large sample of randomly selected persons over the age of 58 years. A number of other vision functions were also assessed in the same persons. The data were used to address the question of whether the decline in stereopsis reflects age-related alterations in cortical stereopsis mechanisms themselves (e.g., disparity detectors) or a degradation of the signal reaching the cortex as a result of alterations in earlier visual components. Two of three vision measures were binocular and thus reflect predominantly the function of the better eye. Results: We find, as many others have reported, that even very coarse stereopsis declines dramatically with age. Despite not having separately assessed each eye, we find that among those selected to have good ocular function there was no significant decline in coarse stereopsis with age. Conclusion: These findings suggest that the enormous decline in coarse stereopsis with age can be accounted for by alterations in early stages of vision processing.

Key Words: aging, spatial vision, stereopsis, disability glare, photostress, Amsler grid

In a recent study of vision function of 900 people aged 58 and older, we found that stereopsis showed substantial decline with age. Other studies also report that stereopsis is poor in the elderly and that there is a strong tendency for stereopsis to decline with increasing age among those in this age group.

What is the cause of this decline of stereopsis with age? Two possibilities immediately suggest themselves. One is a deterioration of the cortical stereopsis mechanisms. Alternatively, the information sent to these mechanisms maybe sufficiently degraded because of age-related changes in the optics of the eye or of the retina, or changes in later ‘prestereo’ stages, so that stereopsis is not supported.

Stereopsis requires the presence of good and approximately equal vision in the two eyes. For example, unilateral amblyopes lack high quality stereopsis, as do persons with equal but low vision in both eyes. Lam et al. report a strong, significant inverse correlation between (naturally occurring) interocular visual acuity differences and stereo threshold in nonaged adults. The association was even stronger in instances in which an interocular acuity difference of one line or larger existed. Not surprisingly, Rubin et al. reported that elderly people who have four or more lines (0.4 log units) of difference in acuity or contrast sensitivity differences of 0.6 log units or more between the two eyes were stereoblind.

However, stereopsis has been reported to decline with age even among persons with good (≥20/20) acuity in each eye and no ocular abnormalities. Brown et al. reported that stereoaclity declined from about 16 sec arc among observers in their 20s to 50s to about 27 sec arc among those aged 60 to 70, a change of less than a factor of 2. This study is consistent with changes in cortical stereo mechanisms underlying the decline in fine stereopsis with advancing age.

Particularly in older patients, dramatic losses in even very coarse stereopsis can be detected in persons with good and equal acuity in the two eyes. For example, Wright and Wormald, using the Frisby stereo test, which has only three coarse disparity steps (85, 170, and 340 sec arc), reported a progressive loss of stereopsis with age even among those with good vision (20/20) in each eye and no history of ocular disease or surgery. Only 50% of their observers aged 65 to 69 detected the finest disparity tested (85 sec arc). Only 23% of those over age 80 could detect the 85 sec arc target. Fifty percent of their older group with good and equal acuity failed to detect even the coarsest disparity (340 sec arc). Does this decline in coarsely
measured stereopsis among older persons with good acuity also reflect changes in the cortical stereopsis mechanisms.

To further address the question of the source(s) of the observed loss in coarse stereopsis with age, we determined the relationship between stereopsis and other measured vision functions. With the exception of the Amsler Grid, all vision testing was done binocularly, and thus is most likely to reflect the function of the better eye. Nonetheless, we find strong associations between stereopsis and measured vision function, suggesting that much of the loss of stereopsis with age may be attributed to changes in the 'prebinocular' visual system. In fact, much of the loss of stereopsis is attributable to retinal and preretal changes in the eye.

METHODS

Study Sample

This study sample has been described in detail elsewhere. Among the tests were Bailey-Lovie high- and low-contrast distance acuity, the Pelli-Robson contrast sensitivity chart, the SKILL Card (near high contrast acuity and near low contrast acuity at reduced luminance), the Berkeley Glare Test (low contrast near acuity with and without surrounding glare), the SKILL glare recovery test (time to recover spatial resolution to a fixed level above previously measured SKILL dark chart threshold), the Farnsworth D-15 color test (standard and Adams’ desaturated versions), temporal resolution and sensitivity, the Frisby stereo test, and the Amsler Grid. Because we are interested in vision under 'real-life' conditions, all testing was done binocularly with habitual correction, with the exception of the Amsler Grid, which was measured monocularly. Table 1 presents the median near visual acuity expressed as logarithm of the minimum angle of resolution (logMAR) (and Snellen equivalents) and log contrast sensitivity of each age group as assessed by the high-contrast light side of the SKILL Card and Pelli-Robson chart, respectively. These data are given to further describe the sample. In most of the figures and analyses to follow, the 75 to 84 and the 85 and older age groups have been combined to assure adequate sample sizes in each age group. The combined 75 and older age group (436 people, 50.9% female, median age 81.9 years) has a median acuity of 0.2 logMAR (20/32) and a median log contrast sensitivity of 1.35.

The Frisby Stereo Test® consists of three plates of transparent plastic that differ in thickness (6 mm, 3 mm, and 1.5 mm). Each plate has four square fields of randomly placed high contrast picture elements. On each plate, one of the four fields contains an area in which the pattern is printed on the other side of the plate, defining a circular area in depth. The thickness of the plate defines the disparity of the stereo judgment (for a given test distance). At the 40-cm test distance used in this study, the disparities of the three plates are ~340, 170, and 85 sec arc. Disparities are not precise, because interpupillary distance was not measured. Plates are tested in order of descending disparity. Only if the subject can pass a test plate is the next finer disparity presented. Thus the number of plates passed is a measure of performance (three plates to zero plates, from best to worst performance). Each plate was presented six times, unless the subject correctly identified the target location on all of the first three presentations, in which case the plate was considered passed and the next plate tested. Five correct identifications out of six presentations were required for passing. The plates were always presented in crossed disparity (circular target in front of background).

RESULTS

Fig. 1a summarizes the stereo results, showing the percentage of people with a given level of stereo performance at each of three age groups. It is apparent that the percentage of people able to pass all three plates (and thus the finest disparity presented) decreases markedly with age. Although the majority (74.4%) of people in the youngest age group can detect the finest disparity (85 sec arc), only 41% of those over age 75 can. For reference, 40 sec arc is considered clinically normal stereopsis threshold. Data of Simmerman suggest a cutoff criterion for normal of ~32 sec arc for the Frisby stereo test. Although our finest disparity tested is more than twice these criteria, many older people cannot detect it. Overall, only 55% of whole sample passed the 85-sec-arc disparity plate. Indeed, more than 30% of those aged 75 and older cannot detect even the coarsest (340 sec arc) disparity tested (pass 0 plates). The dependence of stereo performance on age was confirmed via $\chi^2$ analysis ($\chi^2 = 100.2, p < 0.00001$). Fig. 1b further divides the 75+ age group, presenting data separately for those aged <85 years and those aged 85 years and older. Beyond age 75, there is a very clear

### TABLE 1.

Sample characteristics

<table>
<thead>
<tr>
<th>Age Range</th>
<th>N (%)</th>
<th>Percent female</th>
<th>Median visual acuity (Snellen equivalent)</th>
<th>Median log contrast sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;65 years</td>
<td>133 (15.1)</td>
<td>48.9</td>
<td>0.06 (20/23)</td>
<td>1.85</td>
</tr>
<tr>
<td>65–&lt;75 years</td>
<td>312 (35.4)</td>
<td>59.3</td>
<td>0.10 (20/25)</td>
<td>1.65</td>
</tr>
<tr>
<td>75–&lt;85 years</td>
<td>295 (33.5)</td>
<td>45.8</td>
<td>0.18 (20/30)</td>
<td>1.45</td>
</tr>
<tr>
<td>≥85 years</td>
<td>141 (16.0)</td>
<td>61.7</td>
<td>0.32 (20/42)</td>
<td>1.25</td>
</tr>
<tr>
<td>Total</td>
<td>881</td>
<td>53.6</td>
<td>0.14 (20/28)</td>
<td>1.55</td>
</tr>
</tbody>
</table>
additional decline in stereo with increasing age. About twice as many over age 85 as those under 85 fail all three plates (48.8 vs. 22.4%), and less than half as many aged 85 or older pass all three plates (24.8 vs. 48.8% of those aged 75 to 84).

Comparison between the data in Table 1 and those in Fig. 1 show that the decline in coarse stereopsis with age is much greater than that of spatial vision (acuity and contrast sensitivity). Even among the oldest age group (85+), median acuity is only reduced by a factor of two compared with young healthy subjects, and contrast sensitivity by a factor of four. By comparison, stereopsis is more than 10 times worse than normal in 60.3% of this group.

To address the contributions of ocular and cortical mechanisms to the decline in stereopsis, we examined the association between stereopsis and three other vision measures: the effect of veiling glare on acuity (disability glare), recovery from glare (glare recovery), and integrity of the central visual fields. Age differences on any of these three measures are most likely to reflect changes in the eye as opposed to changes in higher visual structures. More specifically, the impact of veiling glare on spatial vision reflects the amount of scatter produced by the intraocular media, most notably the lens, which is known to become less clear with age and cataract development (e.g.,10,11). Our measure of the impact of veiling glare is the difference between low contrast (10%) acuity measured in the presence of a 3300 cd/m² glare source surrounding the near acuity chart and the acuity for this chart in the absence of the glare source. Glare recovery (also known as retinal photostress), on the other hand, is largely a retinal phenomenon (e.g.,12). The measure used here is the time taken to recover spatial vision to a level two lines above (0.2 log units larger) the previously measured low-contrast, low-luminance (SKILL Card Dark Chart13) visual acuity after 1-min exposure to the 3300 cd/m² glare source. Because we measure time to recover to a fixed level above threshold, the measure reflects only the dynamics of recovery and thus retinal processes; interindividual differences in overall spatial sensitivity (low-contrast acuity), which may reflect changes beyond the eye, do not affect this measure. We used the Amsler grid14 to monocularly assess the integrity of the central 14° of field in each eye. The test target is a white grid printed on a black background. A fixation spot is located in the center of the grid. The subject is asked a series of standardized questions intended to identify irregularities or areas missing in the grid. Results are scored on a scale of 0 to 4, corresponding to no abnormalities to significant vision loss over the entire grid. None of the field losses measured indicated postchiasmal lesions; only changes consistent with field losses in one or both eyes were observed (such as those associated with age-related macular degeneration [ARMD], glaucoma, or diabetic retinopathy).

The sample was divided into persons with good ocular status and those with evidence of compromised ocular status on any of the three tests. The criteria for good ocular status were: for veiling glare ≤ 0.3 log units (three lines) lost (equivalent to a doubling in letter size required for threshold when glare is present); time of recovery from glare ≤ 30 s; and Amsler scores of ≤ 1 on both eyes (0 is no defect, 1 is a single local defect not within 2.5° of fixation). Although Amsler scores of 1 (as opposed to 0) may be obtained erroneously because of nonretinal factors such as bifocal segments, scores of 2 or more reflect real retinal compromise and thus are considered grounds for exclusion. These criteria were chosen to eliminate those with even subtle changes in the retina and ocular media.

Less than half (42.7%, 376 people) of the sample met the criteria for all three measures. The remaining 505 failed one or more of the three criteria. The number of persons failing each test alone or in combinations with other measures is given in Table 2. Four hundred and thirty persons failed to recover from glare in 30 s or less. Less than half this number (199) lost more than three lines of acuity in the presence of glare, and even fewer (145) had significant anomalies on the Amsler Grid. There was considerable overlap among measures, with many subjects failing two of the tests and 71 failing all three. Yet 307 subjects failed only one of the criteria. Of the 307 failing only one test, 238 persons were eliminated solely

FIGURE 1.

Distribution of stereopsis performance among our aged sample. The percentage of subjects with each of the four measured levels of stereopsis is plotted. Performance is given as the number of plates read correctly (0 to 3, worst to best, bottom abscissa) as well as the equivalent stereo acuity (top abscissa). A: performance of the entire sample broken down into three age groups (open bars, aged < 65 years; gray bars, aged 65 to 74; black bars, aged ≥ 75). B: the oldest of the three age groups of panel A has been further subdivided into two age groups to reveal the continued decline among the very old (light gray bars, 75 to 84 years; dark gray, ≥ 85 years).
because of their time to recover from glare, whereas 30 people failed only the Amsler grid and 39 failed only disability glare.

Table 3 shows the percent of people with each level of stereo performance (zero, one, two, or three plates passed) eliminated by any of the criteria. Removing those with any ocular anomalies eliminates nearly all (92.4%) of those with very poor stereo (pass zero plates, worse than 340 sec arc). The percentage of subjects eliminated at better levels of stereo performance declines systematically, but 45.2% of those who pass all three plates are eliminated by the ocular health criteria. This suggests that stereopsis of 85 sec arc can be maintained in the presence of subtle ocular abnormalities. The predominance of persons with relatively poor stereo among those eliminated by the ocular criteria further suggests that impaired stereopsis may be related to ocular problems among the elderly.

Fig. 2 compares the age distribution of the whole sample (black bars) with that of the subsample of 376 meeting the criteria for good ocular status (gray bars). Not surprisingly, the subsample meeting the criteria is younger than the sample as a whole (median ages, 69.7 vs. 74.8 years). The number associated with each of the black/gray histogram pairs in the figure gives the percentage of people of that age eliminated by the three criteria. Only 28.6% of the youngest age group failed to meet all criteria of good ocular health. The selection criteria eliminate larger portions of the older groups. Nearly all (92.2%) of those over age 85 do not meet one or more of these fairly stringent criteria for good ocular health. Because only 11 subjects over age 85 do meet the criteria, they are included in an "age 75 and over group" in the subsequent figure.

Fig. 3 shows the distribution in stereo performance across age for the 376 subjects who meet the criteria on all three measures of ocular status. Comparison between the distributions in Figs. 1a (all subjects) and 3 (those meeting ocular criteria) shows that the decline in coarse stereo with age is much less severe among those persons with clear media and good retinal function. \( \chi^2 \) analysis indicates that, among persons with good ocular function, performance on the Frisby test of stereopsis is not significantly associated with age (\( \chi^2 = 9.96, p = 0.126 \)). For example, just over 65% of persons aged 75 and above with good ocular health detect the finest disparity (pass three plates). The two younger groups of subjects

### TABLE 2.
Number of subjects eliminated by ocular criteria

<table>
<thead>
<tr>
<th>Measure(s)</th>
<th>Number eliminated</th>
</tr>
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<tbody>
<tr>
<td>Recovery time only</td>
<td>238</td>
</tr>
<tr>
<td>Disability glare only</td>
<td>39</td>
</tr>
<tr>
<td>Amsler grid only</td>
<td>30</td>
</tr>
<tr>
<td>Recovery time + Disability glare</td>
<td>83</td>
</tr>
<tr>
<td>Recovery time + Amsler Grid</td>
<td>38</td>
</tr>
<tr>
<td>Disability glare + Amsler grid</td>
<td>6</td>
</tr>
<tr>
<td>Recovery time + Disability glare + Amsler grid</td>
<td>71</td>
</tr>
<tr>
<td><strong>Total eliminated for each measure</strong></td>
<td><strong>505</strong></td>
</tr>
</tbody>
</table>

### TABLE 3.
Percent of persons with each level of stereo performance eliminated by ocular health criteria

<table>
<thead>
<tr>
<th>Stereo performance (# plates passed)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent eliminated</td>
<td>92.4</td>
<td>70.6</td>
<td>59.4</td>
<td>45.2</td>
<td>57.4</td>
</tr>
</tbody>
</table>

**FIGURE 2.**
Comparison of the age distribution of the entire sample (all subjects, black bars) to that of the 376 subjects who pass all three criteria for good ocular function (meet criteria, gray bars). The number of people (ordinate) in each of four age groups (abscissa) is plotted. The numbers associated with each black/gray bar pair indicates the percentage of that age group not meeting all criteria and thus excluded from the later figure. Only 11 subjects in the oldest (\( \geq 85 \) years) meet all three criteria. These subjects are therefore grouped with the younger age group to form an age 75 and over group in Fig. 3.

**FIGURE 3.**
Distribution of stereopsis performance among those aged subjects passing all three criteria for good ocular function. The percentage of subjects with each of the four measured levels of stereopsis is plotted. Performance is given as the number of plates read correctly (0–3, worst to best, bottom abscissa) as well as the equivalent stereo acuity (top abscissa). Performance of the entire sample broken down into three age groups (open bars, \( < 65 \) years; gray bars, 65 to 74 years; black bars, \( \geq 75 \) years). Among this group there is little difference in stereo performance between the age groups.

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show rates of passing all three plates that are similar to that of the oldest group (76.6 and 73.3%). Of those aged 75 or older with good ocular health, <10% fail all plates, and the rate of failing all plates is somewhat lower for the under 65 and 65- to 74-year-old age groups (2.1 and 2.9%). That stereopsis does not decline with age among those with good ocular health suggests that declining ocular status is a major contributor to the age-related loss of stereopsis seen among older people in general.

**DISCUSSION**

The present data replicate those of earlier studies, showing that there is a dramatic decline in stereopsis with age among the elderly. This decline is measured readily using a very coarse test with large disparities and large step sizes. Not only did the percentage of subjects able to detect the finest disparity (85 sec arc) decline with age, but also the percentage of people with very poor stereopsis continued to rise with age. Only 5% of the youngest age group tested could not detect the coarsest disparity, whereas 31% of those over age 75 failed to detect 340 sec arc.

In contrast, among those persons who demonstrate good ocular function, no significant decline in coarse stereopsis with age is observed among our aged subjects. The stereo performance of the group with good ocular function is better than the sample overall. These findings suggest an association between loss of gross stereopsis and degraded ocular function.

It is well known that stereopsis is impaired in persons with significantly reduced central vision in one or both eyes. It would come as no surprise that eliminating such subjects from a random aged sample would improve stereopsis of the group. However, both the group as a whole and the subgroup eliminated by our criteria have good vision by standard measures (median acuity is 20/28).

It would also not be surprising to find a lack of stereopsis in people with advanced cataract. However, this population does not have significant cataract. Twenty six percent (of a subsample of 631 persons for whom medical records are available) had had cataract surgery in one or both eyes prior to testing. Of those remaining, 81% have cataract grade 0 or 1 (graded on a standard clinical scale 0–4) in the better eye. Two percent have grade 3 or more in their better eye, and in the worse eye, only 3.3% have grade 3 or above. Thus, ocular media are fairly clear in both eyes in the vast majority of the population. Nevertheless, 22.5% of subjects tested were eliminated by our sensitive disability glare measure.

Sixteen percent of subjects were eliminated based on Amsler grid scores of 2 or higher. Only 9.7% had scores of 3 or higher in either eye, indicating a defect within the central 5°. Thus, the poor stereopsis of this group overall cannot be attributed to central field anomalies.

In summary, for each of the three tests, a criterion was chosen to eliminate persons with even very subtle abnormalities; for the most part, this population is not visually impaired. Among those who were eliminated, we see an association between stereopsis and ocular visual function. Our criteria eliminated 45.2% of persons who passed all three stereo plates. This reflects the stringency of the ocular criteria and the coarseness of the stereopsis measure. Among those eliminated, we see a progressive worsening of vision function as stereo performance declines. This further suggests a causal association between ocular function and stereopsis.

The photostress and disability glare measures were made binocularly. In most cases, binocularly measured spatial vision largely reflects the function of the better eye and provides no indication of the degree to which the two eyes differ or of the ocular status of the ‘worse’ eye.

In contrast, stereopsis requires the two eyes working in concert and is very sensitive to interocular differences and is more limited by vision of the poorer eye. Nonetheless, we find that selecting subjects based on binocular test results sensitive to very subtle ocular problems (and monocular Amsler grid results) tends to identify those persons whose stereopsis is reduced with age. Our data thus suggest that the decline in stereopsis among the old is related to functional changes in the better eye as well as the worse eye. It is important, however, to bear in mind the recent study by Elliott et al. showing substantial performance improvements after second-eye cataract surgery, revealing much more broadly the importance of the vision of the worse eye.

Using the same stereopsis measure used here, Wright and Wormald found that stereo declined with age even among persons with good and equal vision in the two eyes, defined as 20/20 high-contrast acuity. From this, they concluded that the age-associated decline in stereopsis was caused by changes in cortical binocular mechanisms. In contrast, we find that stereopsis does not decline with age among persons with good vision, defined on the basis of other binocular measures of ocular function and intact central fields in both eyes. The two apparently disparate sets of findings can be reconciled by considering the relative sensitivities of high-contrast visual acuity compared with the measures of ocular function used here. High contrast acuity is known to be relatively robust. High contrast acuity declines less with age than, for example, low-contrast acuity and much less than low contrast acuity in glare or speed of recovery from glare. Further, normal acuity in the presence of compromised visual system health and impaired function (by more sensitive measures such as those used here) have been reported for many age-related diseases, including ARMD, glaucoma, diabetic retinopathy, and media opacities. Thus, it is likely that Wright and Wormald’s good acuity group’s vision function included persons with impaired glare recovery, disability glare, or extrafoveal retinal abnormalities in one or both eyes. The percentage of persons with any of these abnormalities is expected to increase with age and would account for the decline in stereopsis observed in Wright and Wormald’s high-acyuity group. By using more sensitive measures, we more effectively eliminated persons with subtle ocular compromise, and thus saw no decline in grossly-measured stereopsis with age.

Using the Frisby stereo test, an age-related decline in stereopsis was observed in our population as a whole but not among those with good ocular function. The Frisby test is a coarse measure of stereopsis, with only three widely separated test disparities (85, 170, and 340 sec arc at our test distance). It is quite likely that there remains a decline in stereopsis with age in this latter group that is too subtle to be detected using this method, but would be revealed using finer disparity steps.

In contrast to the results of an earlier study, our results indicate that age related declines in even very coarse stereopsis can be accounted for by deficits in the early stages of visual processing. It is
also possible, of course, that persons with ocular problems also have binocularity problems and that the two are not causally related.

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