A Comprehensive Assessment of Visual Impairment in a Population of Older Americans

The SEE Study

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Purpose. The Salisbury Eye Evaluation Project is a longitudinal study of risk factors for age-related eye diseases and the impact of eye disease and visual impairment on physical disability. In this article, the authors report the prevalence of visual impairment in their population and explore the relations among the various measures of visual function.

Methods. A population-based sample of 2520 residents of Salisbury, Maryland, between the ages of 65 and 84 years were enrolled in the study. Twenty-six percent of participants were black. Vision tests included best-corrected Early Treatment Diabetic Retinopathy Study acuity, Pelli-Robson contrast sensitivity with and without glare, Randot stereoacuity, and 60° Humphrey visual fields.

Results. Visual function decreased linearly with age for the acuity, contrast sensitivity, glare, and visual field tests. Stereoacuity remained constant into the mid-70s and declined at an accelerating rate thereafter. Black participants had lower contrast sensitivity, reduced stereoaucity, and worse visual fields, at all ages compared to white participants; however, white participants were more sensitive to glare. The overall prevalence of visual acuity impairment in blacks was 5.6% versus 3.0% for whites, using the traditional United States definition (worse than 20/40 to better than 20/200) and 3.3% for blacks versus 1.6% for whites, using the World Health Organization definition (worse than 20/60 to 20/400). Acuity was correlated moderately with contrast sensitivity, stereoaucity, and visual fields (Spearman rho = 0.50, 0.35, and 0.34, respectively). The correlation between acuity and glare sensitivity was low (rho = 0.12).

Conclusions. Many aspects of visual function, not just acuity, decline with age. Black participants have more visual impairment than do white participants for all tests except glare sensitivity. The prevalence of visual acuity impairment in the Salisbury Eye Evaluation population is lower than that reported by other studies using similar test procedures. Low-to-moderate correlations among vision test scores suggest that several different dimensions of visual function are being assessed. Invest Ophthalmol Vis Sci. 1997;38:557-568.
An initial sample of 4624 persons living in the Salisbury, Approximately half of the eligible subjects who re-
fused to participate in the study agreed to answer a
brief subset of the home questionnaire.

In this article, we describe the distribution of vi-
sion test results according to the major demographic
variables of age, race, and gender. In addition, we
evaluate the relations between visual acuity and other
measures of visual function. To provide estimates of
prevalence of various types of visual impairment, it
is necessary to partition test results into normal and
abnormal categories. Several schemes have been pro-
posed for partitioning visual acuity data. There are
no analogous schemes that have received widespread
acceptance for partitioning other measures of visual
function. Therefore, in this article, we discuss the pre-
valence of visual impairment according to acuity-based
definitions.

METHODS

Subjects

The study sample consisted of 2520 persons tested be-
An initial sample of 4624 persons living in the Salisbury,
Maryland, metropolitan area aged 65 to 84 was drawn
from the Health Care Financing Administration Medi-
care eligibility lists. This sample included 100% of the
identified black residents and an age-stratified random
sample of 58% of identified white residents. No other
ethnic groups were represented. Seven hundred eigh-
teen (16%) of the initial sample were ineligible because
they had died (5.4%), moved out of the area (3.8%),
moved into nursing homes (2.7%), had Mini-Mental
State Examination (MMSE19) scores <18 (2.2%), or
were too ill or bedridden (1.9%). Eighty-five (2%) of
could not be contacted, and 935 (20%) refused to par-

Informed consent was obtained in accordance with
the Declaration of Helsinki using forms approved by
the institutional human experimentation commit-
tee, and a 2-hour in-home interview was administered
to each of the remaining 2886 participants. This was
followed by a 4- to 5-hour clinic examination. Three
hundred forty-seven (12%) of the participants refused
the clinic examination. Clinic examinations were com-
leted on 2520 (88%) of the participants for an overall
participation rate of 65%, excluding the ineligible.
Approximately half of the eligible subjects who re-

Vision Tests

Refraction. Participants were refracted using a
Humphrey Autorefractor. This refraction was used as
the starting point for a full subjective refraction, if
indicated by visual acuity test results (see below). The
subjective refraction followed a protocol that was simi-
lar to that developed for the Beaver Dam Eye Study.8

Visual Acuity. Distance acuity was tested with charts
developed for the Early Treatment Diabetic Retinopa-
thy Study (ETDRS).20 The ETDRS chart conforms to
standards for acuity testing proposed by the National
Academy of Science—National Research Center
Committee on Vision.21 The acuity chart was transillu-
molated with the Lighthouse lightbox (The Light-
house, New York, NY), which maintains chart lumini-
nance at 130 cd/m².

Acuity was tested at 3 m. If the participant was
unable to read the largest letters on the chart, test
distance was reduced to 1.5 m, and testing was re-
peated. This procedure was repeated until an acuity
measure was obtained or the participant failed at a
distance of 1 m. Only five participants were unable to
read any letters with either eye. A strict forced-choice
testing procedure was used: The participant was re-
quired to guess even if the letters appeared illegible
until at least four of five letters on a row were named
incorrectly. Visual acuity was scored as the total num-
ber of letters read correctly and converted to logio
minimum angle resolvable (logMAR) according to the
method recommended by Bailey et al.22 Participants
who did not read any letters arbitrarily were assigned
an acuity of 1.7 logMAR (20/1000).

Acuity was measured separately for the right and
left eyes using the participant’s habitual refractive cor-
rection. If the acuity was worse than 20/40 with either
eye, then a complete subjective refraction was per-
formed using the autorefractor findings as the starting
point. Acuity measurements for the right eye and left
eye were made with different versions of the ETDRS
chart.

Ten participants were unable to identify letters
because of illiteracy, and the Lea Symbols Chart was
substituted. The Lea Symbols Chart has the same lay-
out as the ETDRS chart but uses four pictorial opto-
types instead of letters.23

Contrast Sensitivity. Contrast sensitivity was mea-
sured with the Pelli–Robson letter sensitivity test24 us-
ing the participant’s best refractive correction. The
Pelli–Robson chart consists of 16 groups of three up-
percase letters that are of constant size but vary in
contrast. The groups decrease in contrast by approxi-
mately 0.15 log units, ranging from 90% contrast to
0.5% contrast. The test was administered at 1 m under
controlled room illumination (approximately 100 cd/
m²). Contrast sensitivity was scored letter by letter25
and recorded as log contrast sensitivity (logio 1/con-
trast of letters at the threshold of visibility). When viewed at 1 m, the letters subtend 3°, equivalent to a 20/720 Snellen letter. By using large letters, the contrast sensitivity test is affected minimally by visual resolution factors such as residual refractive error.26

Glare Sensitivity. Glare sensitivity was measured with the Brightness Acuity Tester (Mentor O & O, Norwell, MA). The Brightness Acuity Tester is an illuminated white hemisphere placed in front of the eye, with an aperture through which a test chart is viewed. Contrast sensitivity was measured first without, and then with, the glare light turned on (medium setting, 350 cd/m²) using the participant's best refractive correction and different versions of the Pelli–Robson chart. The glare sensitivity score is the number of letters identified correctly without glare minus the number of letters identified with glare. Unlike contrast sensitivity, for which higher scores indicate better performance, higher glare sensitivity scores indicate worse performance. No contrast sensitivity or glare testing was administered to the 10 participants who were unable to identify letters.

Stereoacuity. Stereoacuity was tested with the Randot Circles test. The test consists of a series of 10 panels, each composed of three circles on a random dot background. There are two images overlayed in each panel. When viewed through polarized glasses, only one image is available to each eye. Small horizontal disparities in each eye's image create a depth illusion. The panels form a graded disparity series from a maximum of 228 arcsec to 17 arcsec when viewed at a distance of 36 cm. The observer's task is to judge which circle in each panel appears to hover above the other circles. The panels are tested in order, beginning with the largest disparity and continuing until there is an incorrect response. Participants wore their habitual near correction.

Visual Fields. Visual fields were tested in each eye using the 81-point, single-intensity screening test strategy on the Humphrey Field Analyzer. This strategy tests points over a 60° (radius) field with a single-target intensity of 24 dB. The background was set to 31.5 apostilbs. The appropriate refractive correction was placed in the trial lens holder during testing of the central 30° but removed for the peripheral 30°. If the fixation losses, false-negative, or false-positive results exceeded 20%, the test was stopped and the participant was retrained before undertaking a new test. Visual field reliability indexes were examined for all tests. If the percentage of false-positives, false-negatives, or fixation losses exceeded 33%, this was taken as an indication of a potentially unreliable test. One or more of these criteria were exceeded by 851 participants (35%), the majority of whom (489, or 20%) had excess fixation losses. This screening protocol is similar to that used in a study of 10,000 drivers in California.28

Data Analysis

Demographic variables, including age at the time of the clinic examination, gender, race, marital status, whether the participant was living alone, and years of education, were compiled from the home interview. A self-assessment of vision status was obtained with the question, “How would you rate your current vision with your glasses on, if you wear glasses, on a scale of 0 to 10, with 10 representing excellence and 0 representing blindness?” Chi-square tests were used to test for differences in demographic characteristics and vision status between participants and refusals.

Distributions of vision test scores were inspected for symmetry. Acuity and visual field scores were skewed highly, necessitating transformations of the data for statistical analyses. Transformation of acuity from logMAR to decimal acuity (e.g., logMAR 0.5 = 20/40 = 0.5) improved symmetry somewhat. However, the interpretation of the logMAR scale is much more straightforward because each line on the printed chart represents an equal step on the logMAR scale. Parallel analyses were performed using logMAR and decimal scales. There were no differences in the results, so acuity is reported in logMAR and conventional Snellen notation. Visual fields were transformed to the square root of the number of points missed. The stereoscopic test presented a different set of analytic problems. A significant proportion of participants (14.3%) failed the test and no type of data transformation could restore symmetry to the distribution of scores. Therefore, we analyzed results separately from those who passed the test at some level of stereoscopic and those who failed.

Linear and polynomial regression analyses were performed to evaluate changes in visual function with age. Analysis of covariance was used to test for differences in visual function by race or gender after adjustment for age. Because age did not interact with other demographic variables in any of the models, we applied a single adjustment for age to both races and both genders.

Polychotomous logistic regression was used to evaluate the association of demographic risk factors with visual acuity impairment. Visual acuity impairment was defined according to the trichotomy of “normal vision” (20/40 or better), “visual impairment” (worse than 20/40 but better than 20/200), and “legal blindness” (equal to or worse than 20/200) commonly used in the American medical–legal system. The trichotomy proposed by the World Health Organization,27 which differentiates “normal vision” (20/60 or better) from “low vision” (between 20/60 and 20/400) and “blindness” (worse than 20/400), also was used. Separate bivariate regressions were performed with each demographic factor listed in Table 1 plus MMSE. Those factors that were significant in
TABLE 1. Demographic Characteristics of Sample

<table>
<thead>
<tr>
<th>Feature</th>
<th>Participants</th>
<th>Refusals*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>2520</td>
<td>1301</td>
</tr>
<tr>
<td>Age at time of recruitment (years)</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>65–69</td>
<td>36.8</td>
<td>32.6</td>
</tr>
<tr>
<td>70–74</td>
<td>31.3</td>
<td>28.0</td>
</tr>
<tr>
<td>75–79</td>
<td>21.0</td>
<td>22.4</td>
</tr>
<tr>
<td>80–84</td>
<td>10.9</td>
<td>17.1</td>
</tr>
<tr>
<td>Gender†</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>42.1</td>
<td>37.5</td>
</tr>
<tr>
<td>Female</td>
<td>57.9</td>
<td>62.5</td>
</tr>
<tr>
<td>Race</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>73.6</td>
<td>74.4</td>
</tr>
<tr>
<td>Black</td>
<td>26.4</td>
<td>25.6</td>
</tr>
<tr>
<td>Education level†</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Less than 6 years</td>
<td>8.4</td>
<td>8.0</td>
</tr>
<tr>
<td>6 to 12 years</td>
<td>63.7</td>
<td>74.7</td>
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<tr>
<td>More than 12 years</td>
<td>28.1</td>
<td>17.4</td>
</tr>
<tr>
<td>Marital status‡</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>57.7</td>
<td>53.3</td>
</tr>
<tr>
<td>Single</td>
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<td>3.2</td>
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<tr>
<td>Widowed</td>
<td>30.9</td>
<td>36.2</td>
</tr>
<tr>
<td>Divorced/separated</td>
<td>8.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Living arrangement‡</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Live with other adult(s)</td>
<td>56.8</td>
<td>51.9</td>
</tr>
<tr>
<td>Live alone</td>
<td>43.2</td>
<td>48.1</td>
</tr>
<tr>
<td>Vision status (10 = excellent; 0 = blindness)</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>0–2</td>
<td>2.6</td>
<td>1.0</td>
</tr>
<tr>
<td>3–5</td>
<td>14.6</td>
<td>15.0</td>
</tr>
<tr>
<td>6–8</td>
<td>43.4</td>
<td>43.7</td>
</tr>
<tr>
<td>9–10</td>
<td>39.5</td>
<td>40.3</td>
</tr>
</tbody>
</table>

* Refusal data for education level, marital status, living arrangement, and vision status based on 843 participants who refused clinic examination but agreed to answer all or part of home questionnaire.
† P < 0.001.
‡ P < 0.05.

The bivariate analyses were included in a multivariate model.

The associations between pairs of vision tests were evaluated with both parametric (Pearson product moment) and nonparametric (Spearman's Rho) correlation. All statistical analyses were performed with Statistical Analysis Software (JMP; version 3.1) on an Apple (Cupertino, CA) Macintosh computer.

RESULTS

Demographics

Demographic characteristics of participants and refusals are listed in Table 1. Those refusing were somewhat older, more likely to be women, and less likely to have completed high school than those who participated. Refusals also were more likely to be widowed or living alone than were participants. There were no significant differences between participants and refusals by race or self-assessed vision status.

Visual Acuity

Figure 1A illustrates the cross-sectional decline in best-corrected visual acuity with age. The graph plots the median score and upper and lower quartiles at 1-year intervals. Data are shown for the better-seeing eye. There was a significant linear decline in visual acuity (i.e., higher logMAR score). Careful inspection of the residuals and comparison of the linear model with models incorporating higher order age terms failed to indicate any departure from this linear trend over the range of ages included in our sample. The regression coefficient was 0.009, which indicates that there was a 0.09 increase in logMAR acuity, or 0.9 of a line loss, per decade.

Female participants were, on average, slightly older than were male participants (73.8 versus 73.1 years, t = 3.34, P < .001). Their visual acuity scores were worse, even after adjustment for age. However, the difference (logMAR —0.01 for men versus 0.00 for women or 20/19 versus 20/20, F = 8.48, P < 0.01) was less than one letter, far smaller than the test–retest variability reported for the tests and of negligible clinical significance.

Figure 2A plots median acuity and upper and lower quartiles at 1-year intervals, stratified by race. Acuity scores for black participants slightly were worse than those for white participants. However, the difference (logMAR —0.01 for white versus 0.02 for black or 20/19 versus 20/21, F = 29.9, P < 0.001) was equal to one and a half letters, still less than test–retest variability.

Table 2 lists the proportion of participants who would be classified as visually impaired or legally blind according to the United States and World Health Organization definitions. The prevalence of visual impairment increased with age past 70 years in white participants and women. The trend was less consistent for black participants and men. Nevertheless, blacks had higher rates of visual impairment than did whites at all ages by either definition.

Contrast Sensitivity

Figure 1B graphs the change in contrast sensitivity with age. The graph plots the median score and upper and lower quartiles at 1-year intervals. Data are shown for the eye with better contrast sensitivity. Contrast sensitivity data were missing for 15 participants, 10 of whom were illiterate. There was a significant linear decline in contrast sensitivity with age. As before, there was no indication of a departure from this linear trend over the range of ages included in our sample. The regression coefficient was —0.011, which indicates that...
there was a 0.1 decrease in log contrast sensitivity, or a 28% decrease in contrast sensitivity, per decade.

Female participants had slightly lower contrast sensitivities than did males; however, there was not a statistically significant difference when adjusted for age (F = 3.1, P = 0.07). There was a significant difference in contrast sensitivity scores between white and black participants (1.60 versus 1.52 log contrast sensitivities, F = 88.1, P < 0.0001). The difference of 0.08 log unit, or approximately 20%, was nearly equal to the loss of contrast sensitivity over a decade of life. Figure 2B plots log contrast sensitivity at 1-year intervals for white and black participants. The difference between the groups is evident particularly in the younger age groups, with blacks having lower scores.

Glare Sensitivity

Figure 1C graphs the increase in glare sensitivity with age. The graph plots the median and upper and lower quartiles at 1-year intervals of the difference between contrast sensitivity without glare and contrast sensitivity with glare. Glare sensitivity data were missing for 50 participants (2%), primarily because of a mechanical failure of the Brightness Acuity Tester. Data are shown for the eye with better glare sensitivity (fewer letters lost with glare). A positive value indicates that the glare source reduced contrast sensitivity, whereas negative scores indicate that contrast sensitivity improved in the presence of glare. The seemingly paradoxical improvement of contrast sensitivity with glare has been reported by other investigators using a similar apparatus and is thought to result from improved visual function at higher light adaptation levels. There was a significant linear increase in glare sensitivity with age. The regression coefficient was 0.1, which indicates that there was a one-letter increase in the number of letters lost in the presence of glare per decade.

Female participants had slightly lower glare sensitivities than did male participants, when adjusted for age (1.5 letters lost for women versus 1.8 letters lost for men, F = 7.1, P < 0.01). However, the difference was less than one-half letter and of negligible clinical

**FIGURE 1.** Average vision test scores are plotted at 1-year intervals. The filled squares (■) indicate median scores and vertical lines extend to upper and lower quartiles. (A) Best-corrected visual acuity in better-seeing eye. (B) Log contrast sensitivity in eye with higher contrast sensitivity. (C) Glare sensitivity scored as number of letters seen without glare minus number of letters seen with glare. Data shown for eye that has the lower glare sensitivity. (D) Stereacuity scored as visual disparity in seconds of arc. (E) Number of visual field points missed in eye missing fewer points. Filled symbols (■) represent data for all participants. Open symbols (□) represent data for participants whose visual fields pass all reliability tests (refer to text).
significance. There was a significant difference in glare sensitivity scores by race, with 2.0 letters lost for whites versus 0.7 letter lost for blacks (F = 127, P < 0.00001). The difference of 1.3 letters was greater than the increase in glare sensitivity over a decade change in age. The disparity between white and black glare sensitivities is illustrated in Figure 2C, which plots glare sensitivity at 1-year intervals stratified by race. The difference between the groups is evident across the age span of the study.

**Stereoacuity**

Three hundred fifty-nine participants were unable to see depth at the largest stereoscopic disparity tested, 450 arcsec, and were classified as stereoblind. Figure 1D graphs the change in stereoacuity with age. The graph plots the median stereo threshold and upper and lower quartiles at 1-year intervals. Stereoblind participants were assigned a stereoacuity of 600 arcsec for graphing purposes. Stereoacuity data were missing for 11 participants, primarily because of difficulties with the polarizing glasses worn during the test. Unlike the other vision tests, stereoacuity did not show a linear decline with age. Instead, the median scores remained constant into the mid-70s, at which point variability increased and stereo threshold increased at an accelerating rate into the mid-80s. In subsequent analyses, separate age adjustments were performed for each half-decade of age.

Excluding those who were stereoblind, there was no difference in average stereoacuity between male and female participants (F = 1.61, P = 0.22), but there was a significant difference in stereoacuity by race (85.8 arcsec for whites versus 96.6 arcsec for blacks, F = 5.55, P < 0.02). The disparity between white and black stereo thresholds is illustrated in Figure 2D, which plots stereoacuity at 1-year intervals stratified by race. The difference between the groups is evident only in the youngest and oldest age groups.

The prevalence of stereoblindness increased significantly with age ($\chi^2 = 64.9, P < 0.0001$) from 10% in the 65 to 69 age group to 26.3% in the 80 to 85 age group. The age-adjusted prevalence of stereoblindness was higher for men than for women (16.1% versus 13.0%, $\chi^2 = 4.6, P < 0.05$) and higher in black participants compared to white participants (19.0% versus 12.7%, $\chi^2 = 15.8, P < 0.0001$).

In Figure 3, stereoacuity is plotted versus the difference in visual function between the two eyes, acuity

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**FIGURE 2.** Average vision test scores plotted at 1-year intervals, stratified by race. The filled symbols (●) indicate median scores for black participants and open symbols (○) represent data for white participants. Vertical lines extend to upper and lower quartiles.
TABLE 2. Prevalence of Blindness and Visual Impairment Based on Best-Corrected Visual Acuity in Better Eye by Age, Race, and Gender

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>United States Number (% of Participants)</th>
<th>World Health Organization Number (% of Participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visual Impairment &gt;20/40 to &lt;20/200</td>
<td>Legal Blindness ≥20/200</td>
</tr>
<tr>
<td>White</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65-69</td>
<td>10 (1.83)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>70-74</td>
<td>10 (1.60)</td>
<td>1 (0.16)</td>
</tr>
<tr>
<td>75-79</td>
<td>14 (3.33)</td>
<td>5 (1.19)</td>
</tr>
<tr>
<td>80-85</td>
<td>21 (8.05)</td>
<td>4 (1.53)</td>
</tr>
<tr>
<td>Black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65-69</td>
<td>7 (3.00)</td>
<td>5 (2.15)</td>
</tr>
<tr>
<td>70-74</td>
<td>13 (6.19)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>75-79</td>
<td>7 (5.30)</td>
<td>2 (1.52)</td>
</tr>
<tr>
<td>80-85</td>
<td>10 (11.11)</td>
<td>4 (4.44)</td>
</tr>
<tr>
<td>Male</td>
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<td></td>
</tr>
<tr>
<td>65-69</td>
<td>6 (1.74)</td>
<td>3 (0.87)</td>
</tr>
<tr>
<td>70-74</td>
<td>12 (3.31)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>75-79</td>
<td>7 (2.93)</td>
<td>5 (2.09)</td>
</tr>
<tr>
<td>80-85</td>
<td>13 (11.3)</td>
<td>4 (3.48)</td>
</tr>
<tr>
<td>Female</td>
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<td></td>
</tr>
<tr>
<td>65-69</td>
<td>11 (2.52)</td>
<td>2 (0.46)</td>
</tr>
<tr>
<td>70-74</td>
<td>11 (2.34)</td>
<td>1 (.021)</td>
</tr>
<tr>
<td>75-79</td>
<td>14 (14.46)</td>
<td>2 (0.64)</td>
</tr>
<tr>
<td>80-85</td>
<td>18 (7.63)</td>
<td>4 (1.69)</td>
</tr>
<tr>
<td>Total</td>
<td>93 (3.69)</td>
<td>21 (0.83)</td>
</tr>
</tbody>
</table>

in Figure 3A and contrast sensitivity in Figure 3B. Both graphs show a sharp rise in stereo thresholds with a three or more line difference between the eyes. A difference of five or more lines virtually guarantees that the participant will be stereoblind. The odds ratio for a 5-line loss of acuity or contrast sensitivity compared to fewer than 5 lines is greater than 40.

Visual Fields

Figure 1E illustrates the change in visual field with age. Solid symbols are data for all participants; open symbols show data only for those subjects whose reliability indexes fell within the conventional cutoff, as described above. The graph indicates the median number of points missed (81 total) and upper and lower quartiles at 1-year intervals. Data are shown for the eye missing fewer points. Visual field data were missing for 56 participants because of equipment malfunction. There was a linear increase in the number of points missed with age. The regression coefficient was 0.9, which indicates that nine additional points were missed per decade. The age trend is the same if unreliable fields are excluded from the analysis.

There was no difference in average visual field score between male and female participants (F = 2.01, P < 0.015). However, there was a significant difference in visual field scores by race (16.7 points missed for whites versus 23.6 points missed for blacks, F = 129, P < 0.0001). The disparity between white and black visual field scores is illustrated in Figure 2E, which plots number of points missed at 1-year intervals stratified by race. The marked difference between the groups is evident across the age span. The results are the same when unreliable fields are excluded (11.6 points missed for whites versus 18.4 points missed for blacks, F = 115, P < 0.0001).

Correlations Among Vision Test Scores

The strength of associations between pairs of vision tests is listed in Table 3. The highest correlation was between acuity and contrast sensitivity (Pearson r = 0.59, Spearman rho = 0.50), followed by the correlation between visual fields and contrast sensitivity (Pearson r = 0.48, Spearman rho = 0.43) or acuity (Pearson r = 0.37, Spearman rho = 0.34). Stereoacuity was correlated moderately with acuity, contrast sensitivity, and visual fields (Spearman rho = 0.35, 0.34, and 0.28, respectively; Pearson r not valid because stereoacuity distribution is skewed highly). The correlations between glare sensitivity and the remaining vision tests were low (<0.15).

The correlations among vision tests are dominated by the large segment of the population who perform extremely well on all of the tests, except perhaps stereoacuity. Another way to look at the overlap between vision tests is to examine the distribution of
FIGURE 3. (A) Stereoacuity is plotted versus the difference in visual acuity between the two eyes. Acuity difference measured in chart lines with one line being equivalent to 0.1 logMAR change. (B) Stereoacuity is plotted versus the difference in contrast sensitivity between the two eyes. Contrast sensitivity difference measured in chart lines, with one line equivalent to 0.15 log unit contrast sensitivity change.

test scores stratified by performance on a different test. Figure 4 graphs the distributions of contrast, glare, stereoacuity, and visual field tests, stratified by visual acuity (20/40 or better versus worse than 20/40). Figure 4A indicates that extremely good contrast sensitivity scores are only obtained from those with good acuity, whereas extremely poor contrast sensitivity occurs only with poor acuity. However, there is considerable overlap in the middle of the distributions. The overlap is greater for the stereoacuity (Fig. 4C) and visual field distributions (Fig. 4D) and greatest for the glare sensitivity distributions (Fig. 4B).

Multivariate Association of Demographic Factors With Visual Acuity Impairment and Blindness

Bivariate analysis indicated that age, gender, race, MMSE, and education were each associated with increased prevalence of visual impairment. When all five factors were included in a multivariate model, age and low MMSE were associated independently with increased prevalence of acuity impairment; age, low MMSE, and black race were associated independently with increased prevalence of legal blindness, according to the United States definitions (Table 4). Similar results were obtained for the prevalence of low vision and blindness according to World Health Organization definitions; however, the confidence intervals were larger because of the smaller numbers of persons who met the definitions for visual impairment.

Prevalence of Visual Impairment Compared to Previous Studies

Several population-based studies have documented the loss of visual acuity with advancing age. Among previous investigations of visual acuity impairment in the elderly, three studies used acuity charts and psychophysical test procedures that were similar to those used in the current study. The Beaver Dam Eye Study examined 4962 residents of Beaver Dam, Wisconsin, between the ages of 43 and 86 years, of whom 2159 (44%) were 65 to 86 years of age. Ninety-nine percent of the population was white. The Baltimore Eye Survey examined 5300 residents of Baltimore, Maryland, 40 years of age and older, of whom 2062 (39%) were 65 years of age or older. Forty-five percent of the sample was black and 55% was white. The Blue Mountains Eye Study examined 3647 residents of the Blue Mountains area in New South Wales, Australia, of whom 1858 (51%) were 65 to 84 years of age. Ninety-nine percent of the population was white.

TABLE 3. Parametric (and Nonparametric) Measures of Association Between Pairs of Visual Function Tests

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Acuity</th>
<th>Contrast Sensitivity</th>
<th>Glare Sensitivity</th>
<th>Stereoacuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast sensitivity</td>
<td>0.58 (0.50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glare sensitivity</td>
<td>0.14 (0.12)</td>
<td>0.02 (0.03)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stereoacuity</td>
<td>—* 0.35</td>
<td>—* 0.34</td>
<td>—* 0.09</td>
<td></td>
</tr>
<tr>
<td>Visual fields</td>
<td>0.37 (0.34)</td>
<td>0.48 (0.43)</td>
<td>0.10 (0.09)</td>
<td>—* (0.28)</td>
</tr>
</tbody>
</table>

* Parametric correlations (Pearson r) were not computed for stereoacuity because the distribution of stereoacuity scores was highly skewed.
Figure 5 shows the observed proportions with visual impairment (acuity worse than 20/40) in the Salisbury population, with 95% confidence intervals. For comparison purposes, we show the expected proportion of individuals in the Baltimore, Beaver Dam, and Blue Mountains populations with visual acuity impairment when applying age-, race-, and gender-specific rates from the other studies. The prevalence of visual acuity impairment in the SEE population is less than that reported in the Baltimore, Beaver Dam, and Blue Mountains studies. Possible reasons for this difference are discussed below.

DISCUSSION

The SEE project is one of the first population-based studies to use multiple tests of visual function. Our results show that, like acuity, contrast sensitivity, glare sensitivity, stereoacuity, and visual fields decline with age. Although there were no clinically significant differences between men and women for any of the vision tests, there were significant differences by race. Black participants had decreased contrast sensitivity, reduced stereoacuity, and worse visual fields. However, white participants were more sensitive to glare. The diminished glare sensitivity of black participants probably can be attributed to reduced light scatter in eyes with darker pigmentation.31 Pigmentation of the iris blocks scattered light from entering the eye, and pigmentation of the fundus reduces intraocular reflection of stray light. Both factors would serve to reduce the veiling luminance caused by the glare source, which reduces contrast sensitivity in the presence of glare.

The prevalence of stereoblindness in this study was high in more than one quarter of the participants 80 to 85 years of age. Although it has been noted that stereoscopic vision declines markedly past the age of 60,32 the reasons for this decline have not been explored fully. Amblyopia is not a likely explanation, because population-based studies have estimated the prevalence of amblyopia at 7% for children and 3% for older adults.33 34 One possibility is related to the fact that stereoscopic vision depends on the coordinated function of both eyes. We hypothesize that the high prevalence of stereoblindness is caused by differential vision loss in the two eyes. Laboratory studies have shown that a difference in visual function (e.g., acuity or contrast sensitivity) between the two eyes...
TABLE 4. Multiple Logistic Regression Analysis of Predictors of Visual Impairment and Blindness

<table>
<thead>
<tr>
<th>United States definitions</th>
<th>Odds Ratio (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual impairment</td>
<td></td>
</tr>
<tr>
<td>(&gt;20/40 to &lt;20/200)</td>
<td>2.6 (1.7, 3.8)</td>
</tr>
<tr>
<td>Legal blindness (≥20/200)</td>
<td>4.5 (1.9, 10.6)</td>
</tr>
<tr>
<td>World Health Organization definitions</td>
<td></td>
</tr>
<tr>
<td>Low vision (&gt;20/60 to =20/400)</td>
<td>6.8 (1.5, 30.8)</td>
</tr>
<tr>
<td>Blindness (&gt;20/400)</td>
<td>3.1 (1.8, 5.2)</td>
</tr>
</tbody>
</table>

is more detrimental to stereoscopic vision than is a uniform depression of function in both eyes. The data shown in Figure 3, that a discrepancy in acuity or contrast sensitivity between the two eyes is associated strongly with stereoblindness, are consistent with the hypothesis.

The prevalence of visual acuity impairment in the SEE population is low compared to that of the Baltimore, Beaver Dam, and Blue Mountains studies. Procedural differences are unlikely to account for the differences. All the studies used similar acuity charts and chart lighting and tested with best refractive correction.

A second potential explanation is differences in participation rates. The participation rate in Salisbury was 66%. Although this rate is higher than in other studies in this age group that include lengthy clinic examinations (e.g., 55% response rate for the Cardiovascular Health Study), it is lower than the 80% participant rates for older participants in Beaver Dam and

FIGURE 5. Filled circles (●) plot the expected proportion of persons with visual acuity impairment (acuity worse than 20/40 in the seeing eye) when applying age-, race-, and gender-specific rates from each of three studies that used acuity testing charts and procedures that were similar to those used in the Salisbury Eye Evaluation (SEE). For comparison purposes, the observed proportions with visual impairment in the SEE is plotted as filled squares (■). Horizontal lines indicate 95% confidence intervals. Comparisons with Beaver Dam Eye Study (BDES) and Blue Mountains Eye Study (BMES) are based on persons 65 years of age and older. Comparisons with the Baltimore Eye Survey (BES) are based on persons 70 years of age and older.
Blue Mountains or the 75% rate for older participants in Baltimore. Abbreviated screening interviews conducted with half the SEE participants who refused the clinic examination in the current study indicate that those who refuse tend to be older than those who participate. This finding also was reported in the Beaver Dam study. Therefore, our estimates of the prevalence of visual acuity loss may be an underestimate of the true prevalence.

A third factor is differences in eligibility criteria. Unlike the Beaver Dam, Baltimore, and Blue Mountains studies, eligibility for the Salisbury study required a MMSE score of at least 18. One hundred four individuals in Salisbury were excluded because of low MMSE scores. Others have shown that cognitive impairment is associated with poor visual acuity, and the current study also found a significant association, even when those with moderate-to-severe cognitive impairment were excluded. Inclusion of cognitively impaired participants probably would have increased the prevalence of vision impairment.

A fourth factor is temporal trends in visual acuity impairment. The studies that reported the highest rates of acuity impairment (Baltimore and Beaver Dam) were conducted from 1985 to 1990. The studies with the lowest rates of impairment (Blue Mountains, SEE, and the recent Rotterdam study) were conducted from 1992 to 1995. The lower rates in the later studies may reflect changes in treatment for eye disease, particularly greater availability and use of cataract surgery. In support of this hypothesis, a comparison of cataract surgery rates indicates that 10.6% of women 65 years of age or older in Beaver Dam had cataract surgery, compared to 23.7% of white women 65 to 84 years of age in Salisbury. The rates for men were 11% in Beaver Dam versus 18.3% in Salisbury.

Consistent with the low rates of visual acuity impairment, the average visual acuity in the SEE population is remarkably good. For participants younger than 70 years of age, the median acuity is better than 20/20 (-0.05 logMAR; 20/18 Snellen equivalent) and rises to slightly more than 20/20 by age 80 (0.08 logMAR; 20/24 Snellen equivalent). Overall, 53% of participants had 20/20 or better acuity.

There are no published population-based data on other forms of vision loss with which to compare our contrast, glare, stereocuity, or visual field findings. Three population-based studies measured contrast sensitivity in older adults. However, none of the studies reported contrast sensitivity data in sufficient detail to allow comparisons with the current findings. The Baltimore Eye Survey evaluated visual fields in adults 40 years of age and older. Although most of the data were collected with the same instrument (Humphrey Field Analyzer), the test array and procedures were substantially different from those used in the current study. There have been no population-based studies of glare sensitivity or stereocuity.

In addition to age and race, low MMSE scores (even above 18) also are associated with visual acuity impairment. The direction of causation cannot be determined from cross-sectional data. Reduced cognitive function may make it difficult to understand and respond appropriately to the task, reduced visual function may lead to cognitive decline, or visual and cognitive impairment may both be indicators of a common neurologic change with age. The association, whatever its cause, highlights the potential for difficulty in conducting visual acuity testing accurately when mental function is compromised. Because the prevalence of diminished mental status is especially high in nursing homes, attention should be paid to separating true acuity impairment from difficulty due to the cognitive demands of vision testing.

In summary, our data show a loss of visual function with age and potentially important racial differences for all tests included in this study. In a population study, the correlation between vision tests is only moderate, suggesting several different dimensions of vision are being assessed. We will use these data and our data on physical disability to construct and validate new norms for each of the vision tests.

Key Words
aging, contrast sensitivity, elderly, glare sensitivity, stereocuity, visual acuity, visual fields, visual impairment

References