Adult Vernier Thresholds Do Not Increase with Age; Vernier Bias Does

J. Vernon Odom, Roberto J. Vasquez, Terry L. Schwartz, and John V. Linberg

Vernier acuity and vernier bias were examined in persons aged 20 to 79 years using a method of adjustments. Vernier bias (mean error) showed a sharp increase between 35 and 45. Vernier acuity (standard deviation or precision of alignment) did not vary significantly with age. These different results indicate the importance of separate evaluation of acuity and bias. Vernier acuity is little affected by minor optical changes that occur with age. Therefore, normal vernier acuity in older persons suggests that the neural substrates which underlie fine-grain discrimination of object location are unaffected by aging over the range investigated. Invest Ophthalmol Vis Sci 30:1004-1008, 1989

Many visual functions decline with age. De Haan first documented the decrease of adult visual acuity with age.1 Subsequently, the same general decline has been observed for visual acuity,2,3 contrast sensitivity,4,6 and dark adaptation.7 The observed decline in the sensitivity of the human visual system may be caused by ocular optical changes, neural changes, or both. As humans age there are many optical and neural changes in the visual system. The pupil becomes more miotic8,9 and the luminance transmission of the ocular media is impaired.10 Presumably, the optical line spread function is also impaired as a consequence. There appears to be a loss of retinal neural cells with age.11-15 Additionally, there are fewer striate cortical neurons as age increases.16 It is difficult to determine if changes in visual function are due to optical or neural processes, because both processes change with age. If one could measure some visual function that was relatively independent of ocular optics, then any observed changes in that performance could be attributed primarily to changes in the neural substrate of that visual function.

Vernier acuity is relatively independent of ocular optics.17,18 It reflects the precision or variability with which an observer can locate one line relative to another. Within the vernier task one may also measure the accuracy (bias or constant error) of the observer’s alignments by determining the difference between the position of the adjustable target at which the subject perceives it to be aligned with the standard (ie, the mean of the subject’s alignment settings) and that at which it is truly aligned by objective measurement.19-25 One of the “hyperacuities,”26 vernier acuity exemplifies the fine-grain spatial discrimination of the visual system. However, unlike visual acuity, contrast sensitivity for high spatial frequencies and stereopsis, it is less affected by optical blur or degradation (see above). Therefore, we sought to determine if vernier acuity or vernier bias (accuracy) would be impaired as a function of age in adult subjects with corrected 20/20 visual acuity, who were otherwise healthy. Observed deficits should be related to neural changes of aging, since vernier acuity is not sensitive to ocular optics.

Materials and Methods

We tested the vernier acuity of ten or more subjects in each of five age ranges: 20–29, 30–39, 40–49, 50–59 and 60–79 years. Informed consent was obtained from all subjects. In the 60–79 age range, five subjects were aged 60–69, and five were aged 70–79. Table 1 indicates the mean age and standard deviation of each age group. All subjects were emmetropic, or their best corrected visual acuity, as tested with a standard eye chart27 at an ambient illumination of 750 lux, was 20/20 or better (no more than two of five letters were missed on the 20/20 line). The eye with the better acuity was tested. If acuities in both eyes were equal, the patient was given a choice of which eye to use during testing. The untested eye was occluded. All of the subjects aged 60 or greater and four of the subjects aged 50–59 were examined in the West Virginia University Eye Clinic. They had full ophthalmic examinations. The examining ophthalmologists indicated that the fundi, external exam and ocular motility were normal.

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All testing was performed in a darkened room with subjects 6 m from a television monitor. Subjects placed their heads in a chin rest against a forehead brace bar. Two vertical white lines, each 10 arc sec wide and 17 arc min high, were generated using an Apple II+ computer and presented one above the other on the television monitor. The bottom line was stationary in the center of the screen while the position of the upper line could be moved horizontally using a potentiometer on a game paddle. The mean luminance of the display was 2 cd/m² and the contrast between the lines and the screen was 90%. Given screen size, resolution and pixel limitations of the Apple II+, the minimum possible horizontal displacement of the top line was 10 arc sec.

Before testing began, subjects were familiarized with the operation of the game paddle potentiometer. The test consisted of 20 trials for each subject. Half of the trials started with the top line offset to the left of the stationary bottom line and the other half with it offset to the right. The distance of the variable line from the fixed line was also varied across trials. Subjects were instructed to move the upper line so that it was exactly above the bottom one. Once they were satisfied that the lines were exactly aligned, they pressed a button on the same paddle. This ended the trial and the computer read the location of the movable top line. Using a calibration formula, the number of pixels between the horizontal locations of the two lines was calculated in arc sees. Positions to the left of the stationary line were assigned negative values while those to the right were assigned positive ones. A subject's bias in vernier judgments was the mean of the 20 adjustments. For statistical purposes the absolute value of the mean error was defined as a subject's bias. Using traditional definitions for method of adjustments, the subject's vernier acuity was the standard deviation of the 20 adjustments and vernier bias was the mean error of the 20 adjustments.

### Table 1. Sample age distribution

<table>
<thead>
<tr>
<th>Age range (yrs.)</th>
<th>Sample size</th>
<th>Mean age</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>12</td>
<td>25.4</td>
<td>3.3</td>
</tr>
<tr>
<td>30-39</td>
<td>10</td>
<td>34.6</td>
<td>2.6</td>
</tr>
<tr>
<td>40-49</td>
<td>11</td>
<td>45</td>
<td>2.5</td>
</tr>
<tr>
<td>50-59</td>
<td>10</td>
<td>53.8</td>
<td>2.44</td>
</tr>
<tr>
<td>60-79</td>
<td>12</td>
<td>68.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>

indicated that the bias of the 40-49, 50-59 and 60-79 groups did not differ from one another, nor did the 20-29 and 30-39 groups differ from each other. The 30-39-year-old group had a smaller bias than the three older groups ($P < 0.05$), and the 20-29 group had a lower bias than each of the two oldest groups ($P < 0.05$).

### Discussion

We observed no statistically significant change in vernier thresholds with age in adults across a 60 year range. This apparent lack of vernier threshold elevation contrasts dramatically with available data that indicate threshold elevation in diverse measures of visual function such as stereopsis, dark adaptation, visual acuity and contrast sensitivity. Vernier bias increased with age; however, the increase was neither monotonic nor linear (see Fig. 2). At 20-39 years, bias measured as the geometric mean was only 3 or 4 arc sec (arithmetic mean of 4 or 5 arc sec), while at 50-79 years it was 12 or 13 arc sec (arithmetic mean was 17-18 arc sec), approximately a 4-fold increase in bias. Diseases which distort the retina can alter bias without changing vernier acuity.

![Fig. 1. Vernier acuity as a function of age. Subject age ranges are plotted on the abscissa and the logarithm of vernier thresholds (ie, geometric means) are plotted on the ordinate. The vertical lines through each point represent one standard error of the mean.](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933377/)
changes are expected to be progressive. In our sample patients argue against this. Moreover, age-related axial high myopia. The ophthalmic exams of our older age decade, increases slightly thereafter, and appears to remain unchanged in the following three decades. We know of no age-related macular diseases which would be manifest at such an early age. Such a rapid step-like change suggests a relationship to other visual changes which occur during the same period, such as presbyopia.

Presbyopia becomes manifest during this period and lens curvature remains unaltered during accommodation, although ciliary muscle activity during accommodation does not diminish with increasing age. Ciliary muscle activity stretches the choroid and presumably the retina over the choroid. In older patients there is an increased rate of refractive error. If the stimulus was slightly blurred for a larger proportion of the presbyopic subjects due to refractive error and the accommodative effort required to focus the lines distorted the retina slightly, vernier bias would increase without increased vernier threshold. Our observation of increased vernier bias without increased vernier thresholds raises an important procedural point. If we had not distinguished between vernier bias (accuracy) and vernier acuity (precision) and had confounded the two in our measurement, then we would have mistakenly concluded that vernier acuity decreased with age. Therefore, it is important to measure vernier acuity and bias independently.

The absence of an effect must always be interpreted cautiously. Below we consider variables that might have obscured a decline in vernier acuity with age. Our population was not random and therefore is not descriptive of the “average” at any age range. Subjects had to have normal visual acuity and no detectable eye disease. As subjects age, those with normal acuities represent a smaller percentage of the population. The mean acuity of our 20–29 group was 20/16 while the average subject of our 60–79 group missed one letter on the 20/20 line of the eye chart. However, unless reduced visual acuity and eye disease are considered normal parts of aging, the criteria we employed are necessary for separating losses in visual functions caused by disease from those caused by normal changes in aging. Most studies of visual function which observed reduced sensitivity in aging use similar criteria. Therefore, the failure of our study to find vernier threshold elevation in advancing age cannot be attributed to our selection criteria.

Our oldest age group may not have been old enough to detect a change that was in fact, present, or our sample size may have been too small to detect an effect. However, any differences that exist between the age groups must be quite small given the standard error of the population mean (ie, 3 arc sec).

Three aspects of our procedures for determining vernier acuity were not optimal. First, we did not employ the stimulus configuration associated with the lowest vernier thresholds, two short lines with a gap between them. We employed two longer lines with no gap between them. However, the experimental purpose was to compare threshold across age, not to determine the lowest possible threshold. Therefore, unless it is assumed that thresholds to some vernier targets are affected by age while others are not, there is no reason that the stimulus choice would invalidate our results. Second, the resolution on our video screen, given the number of pixels produced by the Apple, was 10 arc sec. Third, we employed a method of adjustments rather than a more objective forced choice procedure. In testing older patients, however, there are some advantages of using a method of adjustments. In most forced choice paradigms, stimuli are presented for a fixed time and one must choose on which of two sides or during which of two time
periods a stimulus was presented or was different. The time-limited stimulus presentation and pressures to make choices under uncertain threshold conditions may be confusing or frustrating to the untrained, older observer.\textsuperscript{36,37} In brief, there are procedural advantages in using a method of adjustments in our population which may outweigh the normal advantages of a forced choice procedure. Last, the detection of an age-related change in vernier bias by our procedures suggests that the failure to observe a vernier acuity change cannot be attributed simply to a procedural flaw.

Our results are valid, assuming that our population selection and threshold determination procedures were valid. The failure to find threshold elevation as adults aged contrasts with the more common threshold elevation observed for other visual functions in older subjects. The difference in the relationship of thresholds to age suggests a major difference in the determinants of threshold in vernier acuity versus other visual functions such as visual acuity and contrast sensitivity. Unlike the visual functions previously measured in adults, vernier acuity is not affected by minor optical impairment\textsuperscript{17,18} that usually occurs in older subjects.\textsuperscript{8,10} The resistance of vernier thresholds to blur probably reflects the very different neural processing involved in determining the relative locations of two lines as opposed to determining their visibility.

While it is reasonable to infer that the neural substrates of vernier acuity are relatively unaffected by age, it cannot be concluded from our data that the neural substrates for stereopsis, contrast sensitivity, visual acuity and dark adaptation are normal. Therefore, the results cannot exclude the possibility that neural factors may play a role in threshold elevations observed in other visual functions with age in normal adult subjects. Sloane et al\textsuperscript{6} suggest that threshold elevation of contrast sensitivity with age is not fully accounted for on the basis of optical changes alone. Therefore, the absence of threshold elevation in the present sample of older adults suggests that the neural substrate of vernier acuity is more resistant to the effects of age than the substrates serving other visual functions, such as visual acuity or contrast sensitivity of high spatial frequencies.

Visual acuity and contrast sensitivity are highly dependent upon a sharply focused retinal image, high sensitivity of individual photoreceptors and the density of photoreceptors. As noted earlier, all of these factors are degraded in older subjects. Although the precise foundation of vernier acuity is unclear, individual cells in the cortex,\textsuperscript{36,37} lateral geniculate\textsuperscript{38} and retinal ganglion cells\textsuperscript{39} have been shown to respond differentially to vernier-like stimuli and to have a vernier hyperacuity. In general, the differential responses can be predicted by assuming linear properties of the cells.\textsuperscript{36,38} Recently, a variety of mechanisms subserving vernier performance have been proposed and psychophysical support for them has appeared, including zero crossings,\textsuperscript{40,41} centroids of light distributions\textsuperscript{42,43} or interpolation.\textsuperscript{44} The thread that unites all of these views of vernier acuity is that the relative location of two objects in space first presupposes that the two objects or lines must be detected. Once they are detectable, their relative positions are calculable. In the absence of disease that disturbs object detectability, we were unable to detect any change as one ages in the precision of the ability to identify the relative locations of objects, although there is a decline in its accuracy.

Key words: accuracy, age, aging, object localization, precision, vernier acuity, vernier bias

Acknowledgments

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References

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