Changes in Rod Sensitivity through Adulthood

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Absolute thresholds of 23 subjects 19–61 years of age were determined for three wavelengths at six retinal eccentricities in the horizontal meridian (2.5°–30°). The raw data were corrected for prereceptoral light losses that may be age-dependent. Lens density was estimated for each subject by comparing scotopic spectral sensitivity with the absorption spectrum of rhodopsin. Macular pigment density was estimated by comparing macular sensitivity with peripheral sensitivity. Average dark-adapted pupil size at each age was taken from published values. After correction for these prereceptoral light losses, changes in rod sensitivity with age were not significant at any retinal locus tested. Invest Ophthalmol Vis Sci 30:1738–1742, 1989

The best-known effects of aging on the visual system involve its non-neuronal structures. Accommodation is impaired, the lens becomes less transparent and pupil size decreases. These optical factors combine to reduce visual sensitivity in older subjects. Morphological studies of aged human tissue show that the neural retina, too, is subject to aging. These findings include displacement of photoreceptor nuclei, distortion and convolution of receptor outer segments, reduction in numbers of photoreceptors, structural changes in retinal ganglion cells and reduction in numbers of optic nerve fibers in older eyes.

Here we have looked for age-related changes in visual sensitivity due to changes in the neural retina and not to optical factors. We chose to study the rod system because it is easily isolated, and because rods undergo structural changes with age. Marshall et al report that rod photoreceptor aging is most pronounced in an area they describe as the perimacula. In order to determine whether there are corresponding regional variations in rod system function, we measured sensitivity at six eccentricities in the horizontal meridian. Because it can be difficult to distinguish pathology from normal aging in older eyes we restricted our subjects to those under 61 years of age.

Extensive studies of aging and dark adaptation have shown decreases in absolute sensitivity with age. Because these studies used short-wavelength test spots to optimize rod sensitivity, the decreased sensitivity with age may have been due, in part, to age-related lens changes. Gunkel and Gouras controlled for lens change by using test spots of different chromatic composition and by testing a number of older aphakic subjects. They showed that a red test, which is not affected by age changes in the lens, is less detectable by older subjects. Furthermore, scotopic sensitivity among aphakic subjects dropped slightly with age. In that study, however, natural pupils were used, and the effect of age on sensitivity may have been partially due to age-related reductions in pupil diameter. We have corrected dark-adapted sensitivity for absorptions by lens and macular pigments and for dark-adapted pupil size. Following these corrections, we find no significant effect of age on rod sensitivity.

Materials and Methods

Subjects

Twenty-three subjects between 19 and 61 years of age were tested under dark-adapted conditions. All subjects had received an ophthalmological exam within 1 year of testing, had no evidence of visual abnormality, and had corrected visual acuity of 20/20 or better. All subjects gave written informed consent to participate in the study.

Apparatus

Subjects were tested using a Goldmann-Weekers dark adaptometer. Light from an incandescent source passed through a condensing lens then was rear-projected on a screen in the center of an opaque globe. A rotating sectored disk flashed the test spot for 0.8 sec every 1.6 sec. Fixation was controlled by changing the position of a dim, red, front-projected fixation spot. Test intensity was varied with a 7-log unit linear neutral density wedge filter under manual control. Displacement of the wedge corresponded to

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displacement of a fine marking pin rigidly attached to the wedge housing. The pin could be made to perforate the calibrated recording paper by pressing a spring loaded lever. The raw data, then, were strip chart records of wedge position over time which were later converted to logarithmic units of light intensity.

For these experiments the size of the test spot was restricted by a 1° aperture. Narrow band interference filters (Oriel, Stratford, CT; 8–10 nm wide at half height) controlled its wavelength composition. Thresholds for test spots of 460, 490 and 580 nm were determined at six retinal eccentricities in the horizontal meridian (2.5°, 5°, 10°, 15°, 20°, 30° in the temporal retina). A chin rest positioned the subject’s head, and viewing was monocular with natural pupil.

Calibration

The relative densities of the interference filters used were estimated by making radiometric measurements of the filtered test spot using a photometer/radiometer (United Detector Technology, Hawthorne, CA; Model 40). The neutral wedge was calibrated in nominal 0.5 log unit intervals using the same instrument. Wedge density between calibrated positions was linearly interpolated.

Procedure

Each experimental session began with 30 min of dark adaptation. At the end of this period, the left eye was occluded and testing of the right eye began. Thresholds were estimated using an ascending method of limits. The experimenter started every trial with a low intensity and slowly increased intensity until the observer indicated that s/he could just detect the test spot. At that time the experimenter marked the wedge position, reduced test spot intensity, and began the next trial. Five such threshold estimates were made for each test condition. In initial experiments, five wavelengths (460, 490, 520, 550, 580 nm) were tested at each of six eccentricities (2.5, 5, 10, 15, 20, 30°) in the temporal retina. This required two 1 hr test sessions. Later, testing at 520 and 550 nm was omitted and test time was reduced to a single session. Test wavelength order was randomized across individuals. For each wavelength the six eccentricities were tested in order from center to periphery.

Results

Figure 1 shows the average absolute sensitivities for test spots of three wavelengths measured at six retinal eccentricities. Open and filled symbols show sensitivity for seven subjects under 30 years of age and for five subjects 50 years of age or older, respectively. For all wavelengths and eccentricities sensitivity tends to be lower for the older group of subjects. Repeated measures analysis of variance indicated that at each wavelength tested, sensitivity varied significantly with retinal locus (P < 0.0001). Younger subjects were significantly more sensitive than were older subjects for wavelengths 460 nm and 490 nm (P < 0.02 and P < 0.04, respectively), but not for 580 nm. The interaction between age and stimulus eccentricity was not significant for any wavelength; all eccentricities tested showed similar aging properties.

The true age- and eccentricity-dependence of rod sensitivity might be obscured in these data by prere-
ceptoral light losses which may also be eccentricity- and/or age-dependent. These include light absorption by inert ocular pigments and reduction of pupil diameter. Estimates of lenticular and macular pigment densities were estimated for each individual as described below. Pupil size in the dark was calculated for each subject based on published reports showing that, over the age range of our sample, dark-adapted pupil diameter decreases approximately linearly with age at the rate of about 0.4 mm/decade.12-14

In order to estimate lens and macular pigment densities, a peripheral scotopic spectral sensitivity curve was constructed for each subject by averaging data collected at 15°, 20° and 30°. Macular pigment would not be expected to affect spectral sensitivity at these eccentricities.15,16 Lens density at 460 nm was estimated by comparing the peripheral spectral sensitivity curve of each subject with the Dartnall nomogram peaking at 493 nm to represent the absorption spectrum of rhodopsin.17 The spectral absorption of human rhodopsin in solution is well described by the Dartnall nomogram for wavelengths between 430 and 580 nm.18 The curves were matched at 580 nm where lens absorption is negligible17 and the difference between log relative sensitivities at 460 nm was attributed to attenuation by lens pigment. This is similar to the method used by Norren and Vos.19 The scatterplot in Figure 2 shows the relationship between estimated lens density at 460 nm and age. Lens density increases by about 0.06 log unit/decade of age (r = 0.44). The same procedure was used to estimate lens density at 490 nm. At this wavelength density changes at the rate of 0.03 log unit/decade (r = 0.27).

The density of macular pigment was estimated by determining the difference spectrum between central and peripheral scotopic spectral sensitivity curves. A similar approach involving isolation of the middle-wavelength-sensitive cones rather than the rods was used by Pease and Adams.20 Macular pigment density at 460 and 490 nm 2.5° and 5° from the fovea was estimated by comparing the peripheral spectral sensitivity curves described above with the spectral sensitivity curves obtained at 2.5° and 5°. Again, the peripheral curve was matched to each central curve at 580 nm where macular pigment absorption is negligible.21 Macular pigment density was taken to be the difference between the central and peripheral log sensitivities. Figure 3 shows that estimated macular pigment density at 460 nm 2.5° from the fovea is not significantly correlated with age (r = 0.12). Mean macular pigment densities 2.5° and 5° from fixation, respectively, were 0.19 and 0.13 log unit for 460 nm and 0.10 and 0.05 for 490 nm.

Each individual's scotopic thresholds were corrected for his or her lens and macular pigment densities and for pupil size based on age. The correlation coefficients relating rod sensitivity and age are reduced considerably by correcting for these prereceptoral losses. After correction, analysis of variance revealed no significant differences between the sensitivities of subjects in their 20s and those in their 50s for any wavelength or eccentricity. To examine more fully the age- and eccentricity-dependence of rod sensitivity, straight lines relating corrected sensitivity to age were determined for each of the 18 (eccentricity × wavelength) conditions tested. Correlation coefficients ranged from 0.003 to 0.315; none were signifi-
Fig. 4. Scatterplots of corrected rod sensitivity as a function of age for six retinal loci. The ordinate shows the deviation of each point from the mean value of the sample for each condition. Circles, squares and triangles show data for 460, 490 and 580 nm, respectively. The regression line shown was fit to all the points plotted without regard to wavelength.

Significantly different from zero. Scattergrams illustrating these results are shown in Figure 4. Sensitivity for each condition is plotted relative to the mean sensitivity of the sample for that condition. Circles, squares, and triangles show 460, 490 and 580 nm data, respectively. The lens and macular pigment corrections have eliminated any systematic variation with wavelength; the variation that remains reflects measurement error. Though the effect is nonsignificant, all three wavelengths showed the same pattern of age dependence with eccentricity. Sensitivity decreased with age in the macula by about 0.05 log unit/decade, increased with age at an eccentricity of 10° by about 0.06 log unit/decade, and did not change with age at eccentricities 15°–30°.

Discussion

After correction for prereceptoral light losses there is no significant decline in scotopic sensitivity with age in our sample, under our test conditions. McFarland and colleagues found sensitivity losses of about 0.2 log unit/decade in dark-adapted sensitivity, but much of this effect must be due to their use of a violet test spot and natural pupils. Given that the pupil alone accounts for a sensitivity loss of about 0.05 log unit/decade, our results are consistent with those of Gunkel and Gouras, who reported a sensitivity loss of 0.06 log unit/decade for red lights in both normal and aphakic subjects using natural pupils.

Lens and Macular Pigments

Like others, we find that lens optical density at 460 nm increases approximately linearly from about 0.2 log unit at 20 years of age to about 0.5 log unit by age 60. Our results are also in accord with recent studies showing independence of macular pigment density and age and considerable variation in macular pigment density across individuals. Our values for macular pigment optical density are smaller than those of other workers because our measurements were not taken in the central fovea, where macular pigment is most concentrated.

Retinal Topography of Age-Related Sensitivity Loss

Electron microscopic work shows that age-related changes in rod morphology occur earlier and are most pronounced in an area described only as the "perimacula." These changes include reduction in the number of rods and enlargement of the outer segments that remain. Although the changes in rod sensitivity with age reported here were not significant, there were small variations in rate and direction of...
change which were consistent across wavelengths. Sensitivity decreased slightly with age in the macula, increased slightly with age at an eccentricity of 10°, and did not change with age at eccentricities 15°–30°. In general, however, psychophysical evidence for aging of the rod system appears to be more elusive than that for its anatomical substrate.

Key words: aging, rods, scotopic vision, lens pigment, macular pigment

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References