Age and illuminance effects in the Farnsworth-Munsell 100-hue test

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Seventy-five normal volunteers (20–78 yr) were tested on the Farnsworth-Munsell 100-hue test at each of five illuminance levels. Each cap score distribution was analyzed by fitting a two-cycle sine wave whose amplitude and phase characterize the polarity of the error distribution and its axis. Analysis of these parameters reveals a similarity between tritanlike defects in older groups and those of younger groups at lower illuminance levels. These data are also useful for specifying age norms for the polarity of the error distribution.

I. Introduction

With the advent of widely available low-cost computing facilities, a number of computer programs and algorithms have been published for the analysis of the Farnsworth-Munsell 100-hue (FM 100-hue) test.[1–8] Interpretations of the results of this test are based on the total error score and the degree of polarity of the error distribution when plotted on a polar diagram.

Although computation of the total error score is relatively straightforward, several different algorithms have been suggested for evaluating the polarity and its axis.[1–6] All these methods produce measures that are related to the amplitude of the Fourier component of the error distribution at two cycles per revolution. For example, Kitahara[1] utilizes square-wave filtering (with a two-cycle square wave), and Winston *et al.*[5] employ triangle-wave filtering (with a two-cycle triangle wave) of the error distribution. Both of these methods produce a smoothed error distribution that emphasizes the two-cycle component. Smith *et al.*[2] compute the difference in the square roots of yellow-blue and red-green partial error scores. This method produces an index related to the square root of the amplitude of the two-cycle component.

Several groups have independently exploited Fourier analytic methods. Winston *et al.*[5] and Allen[4] applied Fourier analysis to FM 100-hue error distributions, and each concluded that the relation of the two-cycle component to the zero-order component (mean error) was a useful index of bipolarity. Kitahara's method has been simplified by directly computing the mean error and the amplitude and phase of the two-cycle component.[3,6] Methods for evaluating the statistical significance of these parameter estimates have also been presented.[6] Direct computation of these values is of great savings over most filtering schemes and over Fourier analysis out to several orders.

In the present study, we sought to analyze the effects of aging and illuminance level on the FM 100-hue test. Several studies have quantified the increase in total error score with increase in age and decrease in illuminance.[2,9–12] These studies have also noted the appearance of a tritanlike defect in older groups and at low illuminance levels. Analysis of the amplitude and phase of the second harmonic of the error distribution permits us to quantify these phenomena and to determine norms for this aspect of the test.

II. Methods

A. Observers

Seventy-five normal volunteers within the 20–79-yr age range were enlisted for this study. All were given ophthalmological exams that included fundus exams. Any individual with fundus abnormalities or unclear optic media was excluded from the group. Also excluded were individuals showing evidence of a protan or deutan defect on the Panel D-15, AO-HRR plates or both. All observers had 20/30 or better visual acuity. Table I indicates the age and sex distribution of the sample. At least six males and females were tested in each age category except in the 70–79 age group.

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Table I. Distribution of Age and Sex in Normal Sample

Age	Male	Female	Total
20–29	6	10	16
30–39	7	6	13
40–49	6	6	12
50–59	7	6	13
60–69	6	6	12
70–79	4	5	9
Total	36	39	75

B. Procedure

The FM 100-hue test was administered 6 times to each volunteer. The first administration was binocular at 1800 lx. This served as a practice session to familiarize the individual with the test. Subsequent tests were monocular with the eye used for all five tests chosen randomly at the beginning and the illuminance level chosen randomly without replacement from the set 5.7, 18, 57, 180, and 1800 lx.

The illuminance level was varied by placing neutral filters in a pair of safety goggles from which the glass had been removed. The goggles fit comfortably over the observer's glasses, if any were worn, and provided a binocular field of view of 74 × 37°. With the goggles properly adjusted, all light reaching the observer's eyes passed through the filter. The pupils were not dilated.

The test was illuminated by a MacBeth Executive Daylight source. The illuminance measured with a Pritchard photometer was 1800 lx with a correlated color temperature of 6600 K. For the two lowest illuminance levels, the volunteers were dark adapted with the filters on for 10 min prior to testing. For the other levels, preadaptation was 5 min. Observers were provided with at least one 15-min rest period, aside from dark adaptation; in some cases the tests were spread over two sessions. Completion of all six tests required from 2 to 3 h.

C. Analysis

Each error distribution was scored and plotted by the Kinnear method.[13] The function

$$f(i) = M + A \sin[x(i) + \phi], \tag{1}$$

where $x = 4\pi(i - 1)/85$, i is the cap position, M is the mean cap score error, A is the amplitude, and ϕ is the phase angle, was fit to each cap score distribution using a least-squares method.[3,6] The modulation was computed as the ratio of the amplitude to the mean error (A/M). The axis was determined from the cap positions that corresponded to the peaks of the best-fit two-cycle sine wave, $f(i)$.

III. Results

No significant sex differences were observed in the analysis of the results (see below). Therefore, data were pooled across males and females in each figure.

Figure 1 summarizes the average error distribution as a function of age and illuminance; each column represents a fixed illuminance level and each row a fixed age group. These graphs illustrate the systematic variation of the error distribution with age and illuminance level. The number of errors increased with increasing age and with decreasing illuminance. In addition, the errors were not randomly distributed about the hue circle but progressively became bipolar oriented mostly along a tritan axis. The test is typically administered at levels ranging from 100 to 2000 lx, corresponding to columns 1 and 2 of Fig. 1. For comparison, Verriest's norms for the total error score were collected at 200 lx.[12] Only six observers (or 8%) from column 2 fall outside his 95% confidence limits.

A. Mean Error, Amplitude, and Modulation

Results from fitting the sine waves are shown in Figs. 2–6. In Fig. 2, the top row of graphs shows the mean error score M from Eq. (1) as a function of the illuminance level for three age groups. Results for these groups were qualitatively the same. As the illuminance decreased, M increased. The increase of M with decrease in illuminance was more rapid with increasing age. Since M is a linear transformation of the conventional total error score, this analysis has provided no new quantification of the error patterns.

The second row of Fig. 2 shows that A, the amplitude of the best fitting sine wave, varied in the same fashion as did M. Amplitude was low for high-illuminance levels and increased for low-illuminance levels. The magnitude of the increase grew with age. This measure indicates that the observed increase in errors was not random but tended to be oriented along some axis, producing a bipolar distribution.

The third row depicts the manner in which the modulation varied. This index varied in the same fashion as the previous two indices with one exception. Rather than continuing to increase with decrease in illuminance level, the modulation became approximately constant in older groups. These modulation curves indicate the change in A relative to the change in M. Thus, although A and M both increased with decreasing illuminance in the older groups, they both did so at the same rate.

The data were analyzed using repeated measures analysis of covariance.[14,15] Each of the seventy-five observers completed the FM 100-hue under five illuminance levels, so that the repeated factor was illuminance level. Because this is an ordered variable, we tested for linear and higher-order trends in the illuminance level.[14] In scaling these levels, we used unit differences between adjacent levels for all but the two highest (1800 and 180 lx), where a difference of two units was used. Sex was a grouping factor, and age, used as a continuous variable, was a covariate. Separate analyses were done for the three independent variables: M, A, and modulation. Initial analyses suggested that the variance of residuals increased with the value of the dependent variable, and, therefore, a transformation was indicated. We used the square root of each of the dependent variables, although results were similar whether or not this transformation was employed.

The results of the repeated measures analyses indi-

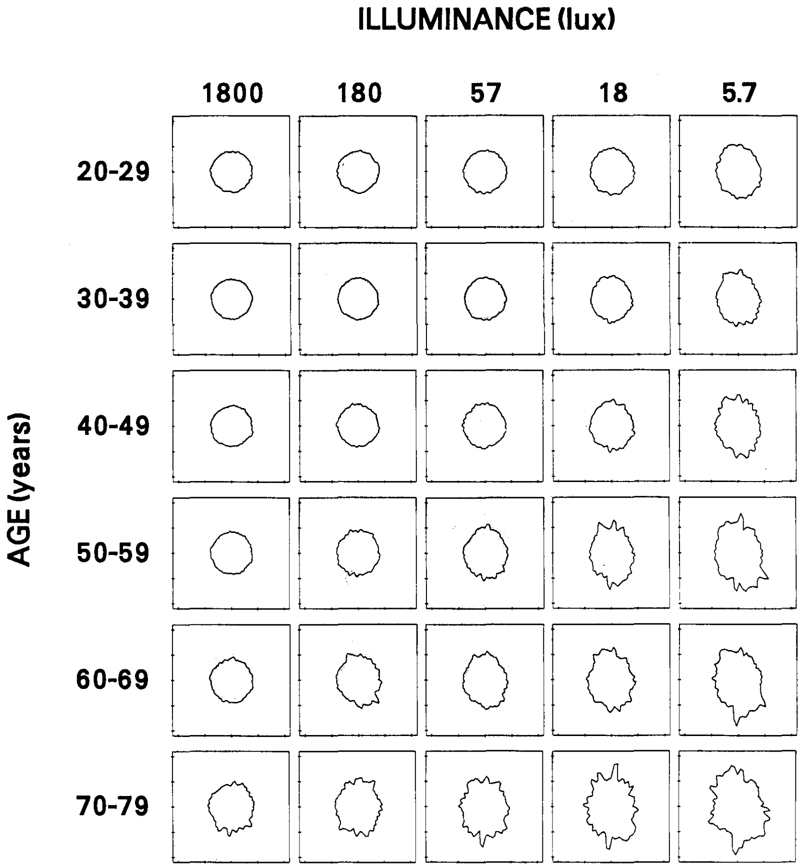

Fig. 1. Average cap score distributions for each age group and illuminance level. Cap position 1 is located at the 12 o'clock position.

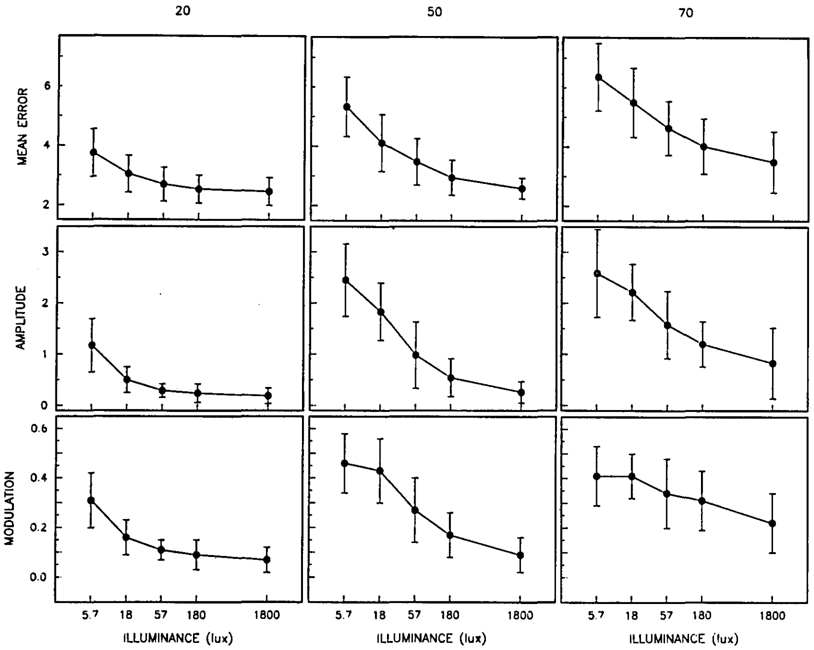

Fig. 2. Top row: mean error as a function of illuminance level in the 20-yr old group (left), 50-yr old group (middle), and 70-yr old group (right). Middle row: amplitude of best fitting two-cycle sine wave as a function of illuminance level; age groups as above. Bottom row: modulation of best fitting sine wave as a function of illuminance level; age groups as above. Error bars indicate ±1 standard deviation.

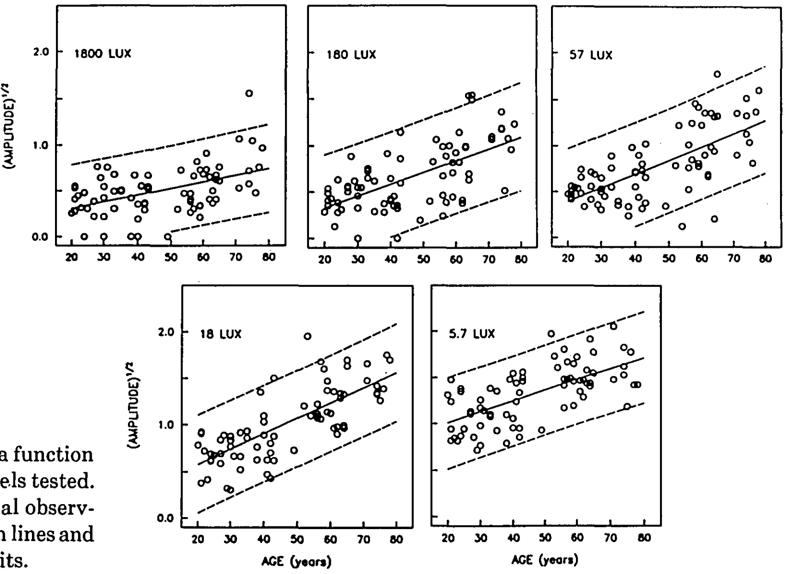

Fig. 3. Square root of the amplitude as a function of age for each of the five illuminance levels tested. Open circles indicate values for individual observers; solid lines are least-squares regression lines and dashed curves 95% prediction limits.

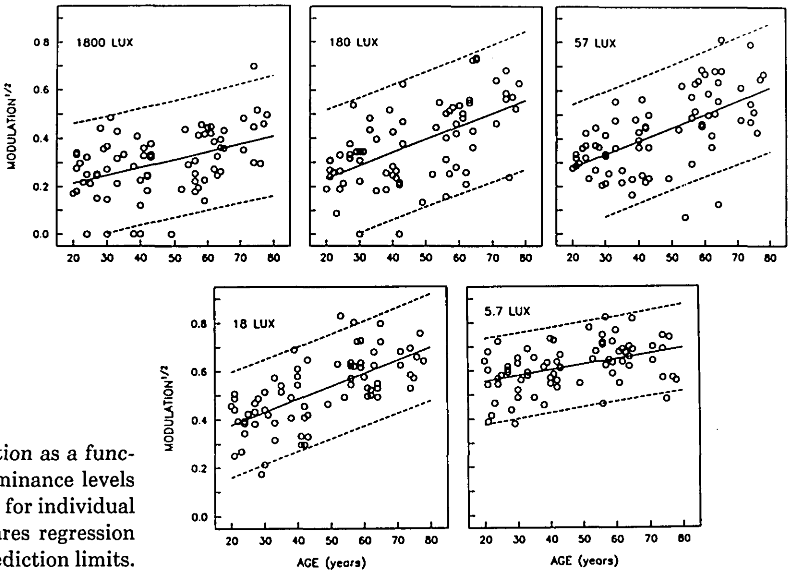

Fig. 4. Square root of the modulation as a function of age for each of the five illuminance levels tested. Open circles indicate values for individual observers; solid lines are least-squares regression lines, and dashed curves are 95% prediction limits.

cated that sex was not significantly associated with any of the dependent variables, while age was strongly associated with each. Each dependent variable was directly and monotonically associated with decreasing the illuminance level ($p < 0.0001$). Although some trends of higher order than linear were also statistically significant, none was more significant than the linear trend. Interpretation of such higher-order trends, in any case, is less straightforward.

Figure 3 shows the square root of the amplitude as a function of age for each illuminance level. The solid lines are the best fitting regression lines, and the dashed curves are the 95% limits within which individual observations are expected to fall. Correlations varied between 0.48 at 1800 lx and 0.75 at 18 lx. Significant differences in the slope were present between illuminance levels. The trend was for the slope to increase in magnitude moving from 1800 to 18 lx but to decrease at the lowest level. This is consistent with Fig. 2 in which the youngest observers seemed immune to the lowering of illuminance except at the lowest level, whereas the older observers showed a steadily increasing amplitude with decreasing illuminance.

Figure 4 shows the regression analysis for the square root of the modulation. Correlations varied between 0.42 at 5.7 lx and 0.66 at 18 lx. Significant differences between the slopes at different luminance levels were present. From 1800 to 180 lx, the slope increased; it stayed nearly constant through 18 lx and decreased at 5.7 lx. The consistency of slope in the midrange of tested illuminances, however, does not imply that the modulation was constant over this range. On the con-

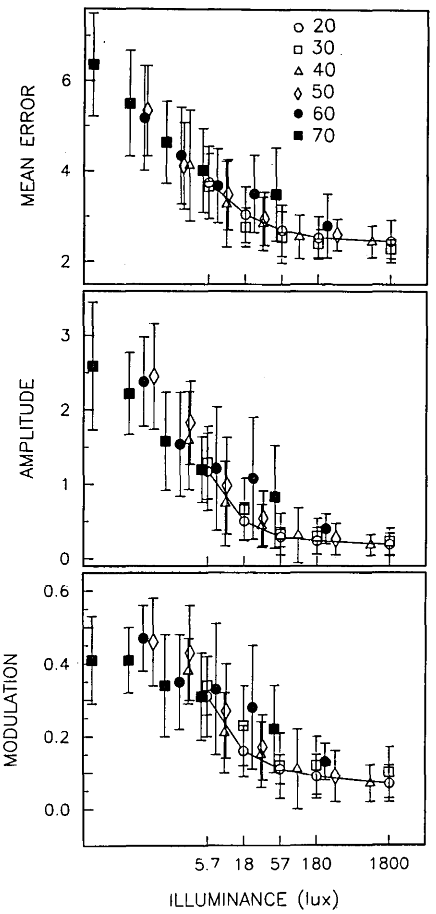

Fig. 5. Top: mean error as a function of illuminance: 20- and 30-yr groups are correctly placed; other groups have been shifted laterally to produce best fit by eye. Solid line is drawn through 20-yr points. Middle: amplitude as a function of illuminance. Lateral shift of each data set is determined by top graph. Bottom: modulation as a function of illuminance. Lateral shift of each data set is determined by top graph. Error bars indicate ±1 standard deviation.

trary, the intercepts of the regression lines increased, indicating an age-independent change due to illuminance.

Instead of a linear regression, one might have fit the data of Figs. 3 and 4 with a two-component curve that is flat between ages 20 and 50 and rises thereafter. Two factors failed to justify such an approach. First, the regressions were similar whether or not a quadratic age term was included. Second, while the slopes were less for the linear regressions restricted to volunteers under 60 yr of age, the significance levels were the same as those when all volunteers were included. It is possible that with a larger sample, this issue might be decided more definitively.

B. Age Illuminance Trade-Off

Qualitatively, the data in Fig. 1 show a trade-off between age and illuminance level. This is indicated by the similarity of error distributions along positive diagonals of the figure. We examined whether the effect of aging could be described as an equivalent decrement in illuminance level by evaluating if the curves of Fig. 2 could be made to align by a lateral shift on the logarithmically spaced illuminance axis. The top box of Fig. 5 represents the data points for the mean error for each age group shifted by eye for best alignment. The line is drawn through the 20–29 age data. For the two oldest groups and at the highest illuminance levels, there is an indication that the data sets do not align. The middle and bottom boxes of Fig. 5 represent data for amplitude and modulation, respectively; their shifts were those determined by the alignment of the data in the top graph.

The alignment of the data for the amplitude and modulation was not as tight as that for the mean error. As with M, the largest deviations were shown by the two oldest groups at the two highest illuminances. Given the size of the error bars about each point, however, the alignment was good enough to suggest that at least some portion of the aging effect is like the effect of attenuation produced by a neutral filter (see Sec. IV). Such a similarity of effects applies to the increase of both total error and polarity of the FM 100-hue error distributions.

C. Axes

None of the above indices reflected the consistency across individuals of the orientation along which the errors were distributed. Phase angles of the best-fit sine waves were transformed into a peak cap number for this analysis. Figure 6 shows the mean peak cap numbers as a function of age at each illuminance level. Since the sine waves fitted to the error distributions were of two cycles, the two peaks determined the values of the cap numbers that form the endpoints of the axis. These endpoints were always 42.5 caps apart on this cyclic scale. The other peak is indicated in Fig. 6 on the right-hand ordinate. Observers with perfect scores were excluded from this figure (five at 1800 lx within the 24–49-yr age range; two at 180 lx within the 20–42-yr age range).

There were no obvious effects of aging or illuminance level on the orientation of the axis of the best fitting sine wave. We analyzed cap number in the repeated measures framework and found that age and sex were not significant. For this analysis, we used the cap number from the left-hand ordinate of Fig. 6, since in this range there was no wraparound of the cyclic scale. The p value for linear trend was 0.01, but it was 0.008 for a quartic trend. Hence interpretation is difficult. Looking at the ten pairwise differences, we found the following significant (at the nominal $p = 0.005$ level) differences: 1800 vs 5.7, 57 vs 18, and 57 vs 5.7 lx, with the lower luminance having on the average the higher cap number.

Recall that modulations for high-illuminance levels and younger groups tended to be low. Possibly, the axes assigned in these cases were due to random errors in performing the test. For the 20-yr group at 1800 lx, plus or minus two standard deviations cover forty caps or nearly the entire range. The mean axis has little

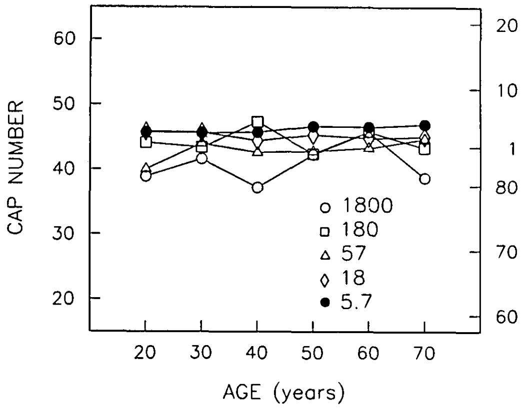

Fig. 6. Axis of polarity in terms of cap number as a function of age with each symbol type representing a fixed illuminance level. Right-hand ordinate is obtained by adding 42.5 (mod 84) to cap numbers of left-hand ordinate.

meaning when the standard deviations are so large, since it simply estimates the center of the range. For older groups and especially at lower illuminances, the standard deviations were considerably smaller, indicating considerable consistency in the position of the axis within each group and (in agreement with Fig. 6) across groups as well. The mean peak cap numbers in these regions vary between 1 and 4 (or 43.5 and 47.5), indicating a tritan axis.

IV. Discussion

Boyce and Simons[10] studied the effects of illuminance over a limited range of performance on the FM 100-hue for three age groups designated as young (30 yr or less), middle (between 31 and 54 yr), and old (55 yr or older). Bowman and Cole[11] evaluated a wider range of illuminance levels but restricted their study to only two age groups, young (20–23 yr) and old (62–74 yr). As in the present study, both investigations demonstrated that lowering the illuminance level impairs color discrimination more in older than in younger groups. By sampling age and illuminance densely and quantifying both the total increase in error and the increase in polarity, we presented a more complete picture of the interaction of aging and illuminance on color discrimination.

To a significant extent, it seems that the effects of aging are similar to the effects of lowering the illuminance level on FM 100-hue performance. Thus the 20–40 age groups at 5.7 lx behave approximately as the 50–60 age groups at between 18 and 57 lx and like the 70-yr group at 180 lx. The effects of illuminance level on the FM 100-hue test might be related to the Bezold-Brucke effect.[16] This phenomenon refers to the change in perceived hue with intensity. At high intensities, bluish and yellowish components of a stimulus become more salient; at low intensities, reddish and greenish components predominate over bluish and yellowish ones. This change in the balance of perceived hue may render yellowish and bluish components of the caps less discriminable, producing a tritanlike defect. This idea raises the question of whether a red-green defect might also be demonstrated at sufficiently high-illuminance levels.

Certain factors do in fact lower the intensity distribution in the aging eye. Older pupils are miotic.[17] This limits the radiant flux directly through a decrease in area of the entrance aperture of the eye but also constrains the entry path to traverse the thickest part of the lens, yielding an additional decrease in transmittance due to Bouguer's law.[18] Based on Fig. 5, such an explanation would require an effective attenuation of light reaching the retina of the 70-yr old group by ~1.5 log units relative to the 20-yr group. This is higher by a factor of 4 than the 0.9 log units estimated by Weale[19] as the short-wavelength reduction at the retina in 70 vs 20-yr old eyes due to a combination of lenticular and pupillary factors. The discrepancy may reflect the fact that the reduction in intensity at the retina is not neutral but considerably greater in the short-wavelength region.

Alternatively, we cannot exclude retinal or motivational factors to explain the effects of aging on FM 100-hue performance. Motivational factors come into play if older groups find the test too tedious or observers find the discriminations too difficult at lower illuminances. Since color differences between adjacent caps are not equal in all quadrants,[20] an oriented error distribution is likely to arise from such factors. It should be emphasized that volunteers were given frequent rests during the course of testing. However, nearly all individuals complained about the difficulty of the test at the two lowest illuminance levels. Finally, retinal factors could represent receptoral or postreceptoral dysfunction with the age of neurons contributing to discrimination in the yellow-blue error axis of the FM 100-hue test. There is evidence suggesting a decline in the density of cones[21,22] and postreceptoral cells[23] with age. Although recent study of the short-wave sensitive cones of the macaque retina did not find statistically significant age-dependent losses of such cones,[24] these results do not exclude postreceptoral losses within the pathways controlled by these cones. Age-associated losses of the longer-wavelength cone types, especially in macular retina, might also interfere with yellow-blue discrimination by the loss of their influence on those postreceptoral sites through which the shortwave cone signals pass.[25]

A. Polarity Norms

Based on data collected at 170 lx, Smith *et al.*[2] have recently presented a set of preliminary norms for a measure of polarity that they devised. Their measure is computed by summing separately over yellow-blue and red-green error scores and then computing the difference between the square roots of these partial error scores. This procedure produces a measure indicating the degree of polarity by its magnitude and the axis by its sign. The computations to obtain this measure are simple, lending it to easy introduction into the clinic. Because of the categorization of the polari-

Table II. Norms for Square Root of Amplitude and Upper 95% Confidence Limit for Prediction of an Individual Observation

Age	1800 lx		180 lx		57 lx		18 lx		5.7 lx	
	$A^{1/2}$	+95%	$A^{1/2}$	+95%	$A^{1/2}$	+95%	$A^{1/2}$	+95%	$A^{1/2}$	+95%
20–29	0.345	0.741	0.389	0.884	0.467	0.945	0.660	1.094	1.069	1.480
30–39	0.417	0.810	0.516	0.990	0.615	1.090	0.824	1.255	1.187	1.595
40–49	0.489	0.881	0.643	1.116	0.763	1.236	0.988	1.418	1.305	1.711
50–59	0.561	0.954	0.770	1.244	0.911	1.385	1.152	1.583	1.423	1.830
60–69	0.633	1.028	0.897	1.374	1.058	1.535	1.316	1.749	1.541	1.950
70–79	0.705	1.104	1.024	1.506	1.206	1.688	1.480	1.918	1.658	2.072

Table III. Norms for Square Root of Modulation and Upper 95% Confidence Limit for Prediction of an Individual Observation

Age	1800 lx		180 lx		57 lx		18 lx		5.7 lx	
	$(\mathrm{Mod})^{1/2}$	+95%	$(\mathrm{Mod})^{1/2}$	+95%	$(\mathrm{Mod})^{1/2}$	+95%	$(\mathrm{Mod})^{1/2}$	+95%	$(\mathrm{Mod})^{1/2}$	+95%
20–29	0.231	0.436	0.260	0.496	0.307	0.527	0.404	0.586	0.567	0.716
30–39	0.263	0.467	0.314	0.549	0.363	0.581	0.457	0.639	0.591	0.739
40–49	0.296	0.499	0.368	0.602	0.419	0.637	0.511	0.692	0.614	0.762
50–59	0.328	0.532	0.422	0.657	0.475	0.693	0.564	0.745	0.637	0.785
60–69	0.361	0.566	0.476	0.712	0.530	0.750	0.618	0.800	0.661	0.810
70–79	0.394	0.600	0.530	0.769	0.586	0.808	0.671	0.855	0.684	0.834

ty as either red-green or yellow-blue, there is some trade-off between orientation of the error distribution and magnitude of its polarity. This ought to be a problem, however, only in rare cases.

Using the data from our 180-lx condition, we compared the axis of Smith *et al.* to the square root of the amplitude and have found that the two measures are significantly correlated ($r = 0.93$). The high value of correlation suggests that both measures capture the same aspect of the error distribution.

Although the number of volunteers in the oldest group ought to be increased, the data in Figs. 3 and 4 could serve as norms for the strength of the second harmonic of FM 100-hue error distributions. These data could then be used to determine if the polarity of a particular distribution lies outside the limits for that age group and illuminance level. The mean values and 95% confidence limits for the square roots of the amplitude and modulation are given in Tables II and III for each age group and illuminance level. These values will be of use to anyone contemplating the type of sine-wave analysis of the FM 100-hue discussed in this paper.

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References

1. K. Kitahara, "An Analysis of the Farnsworth-Munsell 100-Hue Test," in *Colour Vision Deficiencies*, Vol. 7, G. Verriest, Ed. (Dr. W. Junk, The Hague, 1984), p. 233.
2. V. C. Smith, J. Pokorny, and A. S. Pass, "Color Axis Determination in the Farnsworth-Munsell 100-Hue Test," Am. J. Ophthalmol. **100,** 176 (1985).
3. K. Kitahara, "A new analysis of the Farnsworth-Munsell 100-Hue Test," Nippon Ganka Gakkai Zasshi **89,** 32 (1985).
4. D. Allen, "Fourier Analysis and the Farnsworth-Munsell 100-Hue Test," Ophthal. Physiol. Opt. **5,** 337 (1985).
5. J. V. Winston, D. A. Martin, and J. R. Heckenlively, "Computer Analysis of the Farnsworth-Munsell 100-Hue Test," Doc. Ophthalmol. **62,** 61 (1986).
6. K. Knoblauch, "On Quantifying the Bipolarity and Axis of the Farnsworth-Munsell 100-Hue Test," Invest. Ophthalmol. Vis. Sci. **28,** in press (1987).
7. M. J. C. Crabbe and L. S. Mengher, "A BASIC Computer Program for Analysis of the Farnsworth 100-Hue Test," Ophthal. Physiol. Opt. **5,** 81 (1985).
8. T. Benzschawel, "Computerized Analysis of the Farnsworth-Munsell 100-Hue Test," Am. J. Optom. Physiol. Opt. **62,** 254 (1985).
9. G. Verriest, R. Vandervyvere, and R. Vanderdonck, "Nouvelles recherches se rapportant a l'influence du sexe et de l'age sur la discrimination chromatique, ainsi qu' a la signification pratique des resultats du test 100 Hue Farnsworth-Munsell," Rev. Opt. Theoret. Instrum. **41,** 499 (1962).
10. P. R. Boyce and R. H. Simons, "Hue Discrimination and Light Sources," Light Res. Technol. **9,** 125 (1977).
11. K. J. Bowman and B. L. Cole, "A Recommendation for Illumination of the Farnsworth-Munsell 100-Hue Test," Am. J. Optom. Physiol. Opt. **57,** 839 (1980).
12. G. Verriest, J. V. Laethem, and A. Uvijls, "A New Assessment of the 100 Hue Total Scores," in *Doc. Ophthalmol. Proc. Ser. 33*, G. Verriest, Ed. (Dr. W. Junk, The Hague, 1982), p. 199.
13. P. Kinnear, "Proposals for Scoring and Assessing the 100-Hue Test," Vision Res. **10,** 423 (1970).
14. B. J. Winer, *Statistical Principles in Experimental Design* (McGraw-Hill, New York, 1971).
15. W. J. Dixon, Ed., *BMDP Statistical Software* (U. California Press, Berkeley, 1983), p. 359.
16. L. M. Hurvich, *Color Vision* (Sinauer, Massachusetts, 1981).
17. J. H. Carter, "The Effects of Aging on Selected Visual Function: Color Vision, Glare Sensitivity, Field of Vision and Accommodation," in *Aging and Human Visual Function*, R. Sekuler, D. Kline, and K. Dismukes, Eds. (Alan R. Liss, New York, 1982), p. 121.
18. G. Wyszecki and W. S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae* (Wiley, New York, 1982).
19. R. A. Weale, *The Aging Eye* (Harper, New York, 1963).
20. R. Lakowski, "Theory and Practice of Colour Vision Testing. Part 2," Br. J. Indust. Med. **26,** 265 (1969).
21. J. M. Ordy, K. R. Brizzee, and J. Hansche, "Visual Acuity and

Foveal Cone Density in the Retina of the Aged Rhesus Monkey," Neurobiol. Aging 1, 133 (1980).

22. C. Yuodelis and A. Hendrickson, "A Qualitative and Quantitative Analysis of the Human Fovea during Development," Vision Res. 26, 847 (1986).
23. A. G. Balazsi, J. Rootman, S. M. Drance, M. Schulzer, and G. R. Douglas, "The Effect of Age on the Nerve Fibre Population of the Human Optic Nerve," Am. J. Ophthalmol. 97, 760 (1984).
24. F. M. de Monasterio, J. K. Newlander, E. P. McCrane, and S. J. Schein, "Density Profile of Blue-Sensitive Cones Along the Horizontal Meridian of Macaque Retina," Invest. Ophthalmol. Vis. Sci. 26, 289 (1985).
25. E. N. Pugh, Jr., "The Nature of the pi-1 Colour Mechanism of W. S. Stiles," J. Physiol. 257, 713 (1976).

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19–23 October 1987 ANNUAL MEETING OPTICAL SOCIETY OF AMERICA, Rochester Information: Meetings Department at OSA

20–23 October 1987 WORKSHOP ON OPTICAL FABRICATION AND TESTING, Rochester Information: Meetings, Department at OSA

26–28 October 1987 TUNABLE SOLID-STATE LASERS TOPICAL MEETING, Williamsburg Information: Meetings Department at OSA

25–27 January 1988 CONFERENCE ON OPTICAL FIBER COMMUNICATION, New Orleans Information: Meetings Department at OSA

27–29 January 1988 CONFERENCE ON OPTICAL FIBER SENSORS, New Orleans Information: Meetings Department at OSA

12–14 April 1988 OPTICAL INTERFERENCE COATINGS TOPICAL MEETING, Tucson Information: Meetings Department at OSA

25–29 April 1988 CLEO 88, CONFERENCE ON LASERS AND ELECTRO-OPTICS, Anaheim Information: Meetings Department at OSA

September 1988 SHORT WAVELENGTH COHERENT RADIATION TOPICAL MEETING, Cape Cod Information: Meetings Department at OSA

31 October–4 November 1988 ANNUAL MEETING OPTICAL SOCIETY OF AMERICA, Santa Clara Information: Meetings Department at OSA

19–23 February 1989 CONFERENCE ON OPTICAL FIBER COMMUNICATION, Dallas Information: Meetings Department at OSA

24–28 April 1989 CONFERENCE ON LASERS AND ELECTRO-OPTICS, Baltimore Information: Meetings Department at OSA

24–28 April 1989 INTERNATIONAL QUANTUM ELECTRONICS CONFERENCE, Baltimore Information: Meetings Department at OSA

15–20 October 1989 ANNUAL MEETING OPTICAL SOCIETY OF AMERICA, Orlando Information: Meetings Department at OSA