Visual Performance Data for 156 Normal Observers of Various Ages

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SINCE 1959, the Illuminating Engineering Society has evaluated illumination needs of different visual tasks in terms of a system developed by Blackwell[1] which involves standard performance data for a 4-minute luminous disc task exposed for one-fifth second, and a method of evaluating the difficulty of various other tasks in terms of a disc task having equivalent visibility. During the past decade, considerable effort has been devoted to verification, validation, and extension of the method.[2] All this work has involved the use of test observers believed to possess near optimal visual performance potential. The observers were drawn nearly exclusively from the population of university students in their twenties without any known ocular abnormality or visual impairment.

In the original conception of the experimental plan of this work, the so-called "normal young adult observer" was chosen for the following reasons: The population of such observers was believed to be more nearly homogeneous than the population as a whole, thus reducing the number of observers needed to obtain an estimate of the average visual performance potential of the group under study. This group of observers was believed to have the greatest visual performance potential of any group to be found in the population. Thus, illumination needs based upon such a group would represent a conservative estimate for the population as a whole. Finally, observers in this group were most readily available for the research studies conducted by Blackwell and his colleagues, all of which have been carried out in University laboratories.

Some years ago, the present authors began a comprehensive effort to extend these visual performance data to include a larger portion of the population as a whole. As in the case of the young adult observers, the task has involved use of the 4-minute luminous disc, presented for a one-fifth-second exposure duration.

Early studies by Weston,[3] Balder and Fortuin,[4] and Guth[5] had shown that visual performance is reduced as observer groups increase in age. Thus, in planning our study, we had every reason to expect to find differences in visual performance with our standard task which were correlated with age. Our own view was that age *itself* does not alter visual performance potential. Rather, increasing age is accompanied by abnormalities in the physiology of the eye and visual system which reduce visual performance potential. Some of these abnormalities exist to some degree in the young adult and become more pronounced with age. Others develop most commonly with advancing age. Thus, the population as a whole may be conceived as possessing a distriblution of abnormalities differing in kind and amount, all of which influence visual performance to some extent. Assessing such a population requires very large numbers of observers if they are selected randomly. We have chosen to reduce the magnitude of the task of assessing the population by taking non-random samples selected on the basis of our knowledge of the characteristics of the population as a whole.

The present study has been limited to 156 observers of ages varying from 23 to 68 years. All observers are classified as "normal," signifying that they were free from ocular defects discernible under the usual clinical examination.

Our original classification of an observer as "normal" required him to have a visual acuity of 20/20 with or without refractive correction. However, we reconsidered this decision when we discovered how few people over the age of 20 are actually corrected to 20/20 acuity. Accordingly, we made a small study in which we compared visual performance as a function of luminance for a few observers with their visual acuity corrected in the usual manner as compared with the performance of the same observers corrected more carefully to 20/20. We found that visual acuity re-

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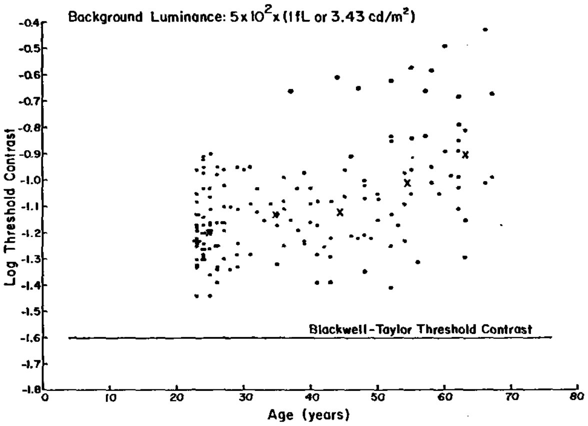

Figure 1. Scatter plot for background luminance: 5 x 10^2 x (1 fL or 3.43 cd/m^2).

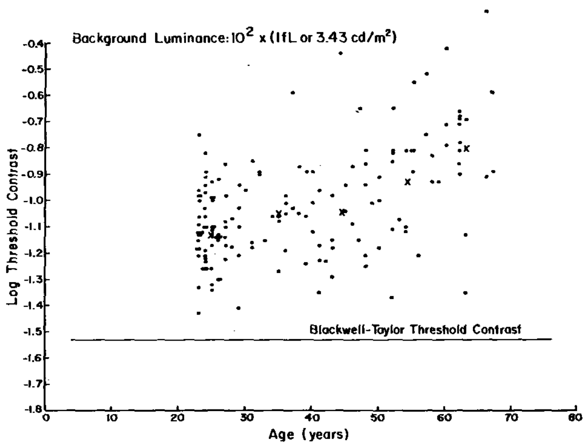

Figure 2. Scatter plot for background luminance: 10^2 x (1 fL or 3.43 cd/m^2).

duced to 20/30 had no effect on the results in our experiment, but that a reduction to 20/40 did cause a reduction in visual performance. Therefore, we included observers with 20/30 visual acuity in our study and eliminated all data obtained on observers with lower acuity. Such normal observers become increasingly rare as aging advances. Thus, we cannot claim that our observer groups represent "average" observers of different age groups. Rather, they almost certainly represent observers of the different age groups having optimal visual performance potential for each age.

Our long-range research plan necessitates study of the effect different abnormalities of the eye and visual system have on our visual performance measure. Once these data are complete, we may use medical statistics on the incidence of abnormalities to estimate the visual performance potential of various age groups. Finally, we may use the population frequencies of the different age groups to estimate the visual performance potential of the population as a whole.

The early studies of normal young adults were made with a laboratory procedure developed by Blackwell,[6] known as the forced-choice method. This method has been shown to be a very sensitive and stable measure of visual performance potential. However, it is exceptionally time-consuming. Hence, it was obligatory that we utilize a much less cumbersome procedure for the study of the comparatively large groups we required for the present purpose. After some experimentation, we fell back on the classical method of adjustment to threshold as most suitable for our purpose. We have carried out special data analyses to relate the data obtained by this method with data obtained by the forced-choice method. As we shall see, it is possible to "graft" our new experimental data onto the existing body of data for the 4-minute disc task.

THE MAIN STUDY

Procedure

For each of our selected observers we obtained a curve of threshold contrast as a function of background luminance over a range from 0.001 to 500 fL (0.003 to 1710 cd/m^2). This was necessary to allow us to check the shape of the function relating these variables. In order to do this we used an instrument of our own design called the Discriminometer. The following are those characteristics which are relevant to the present study. The observer sits in an enclosed booth with his chin on a chinrest and his forehead on a forehead rest and views a white translucent screen three feet (0.91 m) away, 17 inches high by 13 inches wide (43 by 33 cm), at the end of an enclosed box painted white. This screen is illuminated by a projector mounted outside the box to provide a circular background of 20° visual angle. Onto the center of this screen a disc 4 minutes in visual angle is produced by transillumination through the back of the screen. Its color is matched to the color of the background by use of a No. 5900 Corning filter. A shutter provides a one-fifth second exposure of this incremental disc or target every one and two-thirds seconds. A click indicates when the disc is presented. To ensure foveal fixation, a diamond pattern of four small bright spots is projected onto the screen, centered on the location of the target. These fixation lights are separated from the target by 24.3 minutes visual angle, a distance determined by previous experiments to be in the range of those providing the most stable fixation without affecting the visibility of the task. The luminance of the fixation lights can be varied by adjustment of a continuous neutral density wedge under the control of the observer. The luminance of the target is varied by a linked double linear wedge of Chance glass whose density is linear over a range of about nine log units. This wedge is under the control of either the experimenter or the observer. In the present experiment, the observer adjusts the wedge continuously to maintain the target at threshold visibility as background luminance varies. The total range of adjustment covers about three log units of the wedge over the entire range of background luminances studied.

The luminance of the background is also varied by a linked double linear wedge of Chance glass, but this wedge is motor-driven over a range of 5.7 log units

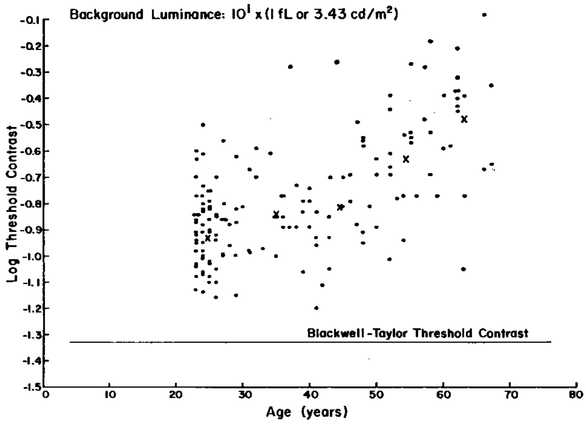

Figure 3. Scatter plot for background luminance: 10^1 x (1fL or 3.43 cd/m²).

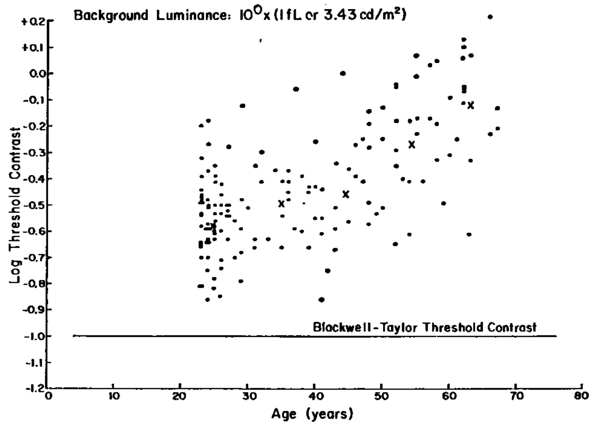

Figure 4. Scatter plot for background luminance: 10^0 x (1 fL or 3.43 cd/m²).

required for our experiment. A switch allows a reversal in direction of movement of the wedge so that the luminance of the background can start at either the highest or lowest level and stop at the opposite end.

The speed of the motor and therefore the rate of change of the luminance of the background was determined by an experiment designed to indicate what rate of change in the background luminance produces the same increment thresholds as separate states of equilibrium adaptation. To do this we obtained thresholds for a number of fixed background luminances to which observers were completely adapted and compared these to the increment thresholds of the same observers when the luminance of the background was changing at different rates. By means of these preliminary experiments we developed our standard procedure which calls for five minutes of adaptation by the observer to the highest background luminance, approximately 500 fL (1710 cd/m²), followed by a period of 30 minutes over which the motor reduces the background luminance, 5.7 log units. Then the motor is reversed and the background is gradually increased in luminance over a period of 30 minutes until it returns to its initial level.

The output of a potentiometer linked to the background wedge is fed into the x-axis of an x-y plotter which has been calibrated to plot on graph paper the log luminance (fL) of the background directly. The target or increment wedge feeds into the y-axis of the x-y plotter and is also calibrated to plot the log luminance (fL) of the increment. Thus the experimenter can observe a continuous plot of the observer's response throughout the whole test.

The observer is seated in the booth where the seat level and chin and arm rests are properly adjusted so that he can look straight at the screen with both eyes. He wears whatever correction he needs for the three-foot distance of the screen as indicated by the ophthalmological examination. The machine is turned on and he is instructed as follows: "Look directly at the small flashing light in the center of the four fixation lights. Adjust the luminance of the small flashing light until you can just barely tell there is something there. You don't have to be able to tell anything about it except that there is something there. During the test the background will very gradually darken and this will make the flashing light easier to see. For this reason, you will have to adjust the luminance of the flashing light continually in order to keep it as dim as possible and still just be able to tell there is something there. If you make it too dim, turn the knob to make it brighter. If you make it too bright, turn the knob to make it dimmer."

The observer is then allowed to adjust the luminance of the flashing disc to his threshold while he is adapting to the background luminance. The sequence of the test is explained and the observer is instructed to dim or brighten the fixation lights to keep them clearly visible but not too bright. Reminders are given throughout the test.

The standard protocol is followed: namely, five minutes adaptation to the highest background luminance, a signal warning the observer to begin adjusting the luminance of the disc to threshold, and 30 minutes of motor-driven reduction of the background luminance by 5.7 log units. The subject is warned, the machine is reversed, and then the background luminance is gradually increased over 30 minutes until the original luminance is reached.

As noted, the observer's adjustment of the luminance of the incremental disc is continuously recorded as a function of the log luminance of the background. The resultant data consist of two continuous curves of the observer's increment threshold in log fL as a function of the luminance of the background in log fL, one obtained for a gradually decreasing background luminance and one for a gradually increasing background luminance. An average curve is drawn through each of these. Log increment threshold values are then read off at discrete background luminance values of 0.5-log unit intervals except for the two highest values which are 0.2 log units apart. These values are averaged for the two curves and then are converted to threshold contrast values by the formula according to Blackwell[7]:

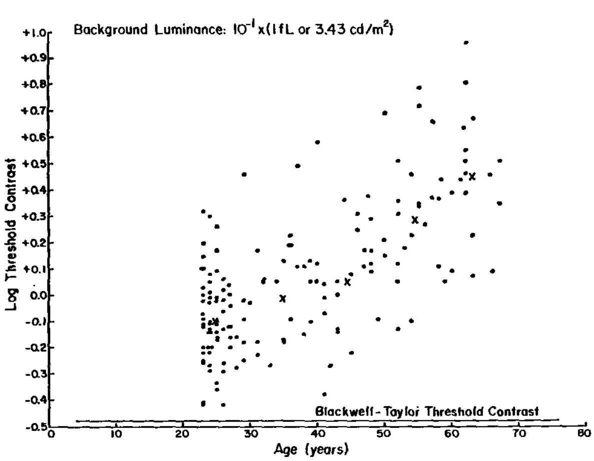

Figure 5. Scatter plot for background luminance: 10^{-1} x (1 fL or 3.43 cd/m²).

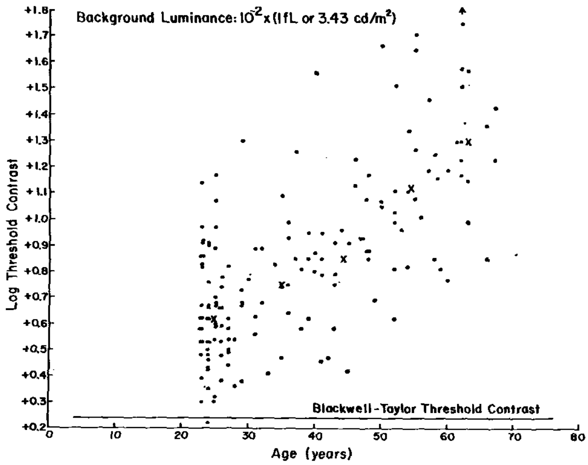

Figure 6. Scatter plot for background luminance: 10^{-2} x (1fL or 3.43 cd/m²).

$C = \frac{\Delta L}{L}$ where C is the contrast, ΔL is the incremental luminance of the disc and L is the luminance of the background. Thus the data for each observer take the form of a curve plotted from a series of values of log C as a function of log L representing an average of two initial curves.

Results

The observers were divided into age groups of 10-year spans as follows: 20-30, 30-40, 40-50, 50-60, 60-70. Tables were made of values of the average log threshold contrast for each observer at each of the above-described discrete values of log background luminance. These log values were averaged, giving a geometric mean for each age group, thus minimizing the effect of extreme values on the mean. The values obtained in this way were subjected to a slight correction based upon the properties of the distributions of individual values as explained subsequently. The corrected mean values were used to construct curves showing the resultant log threshold contrast as a function of log background luminance for each age group. Scatter plots of the individual values of log threshold C were also constructed at selected log background luminances covering the whole range. It should be noted that the number of observers in each of our arbitrary age groups is not equal and, indeed, only for the age group 20-30 do we feel that we have enough data to consider our results a valid estimate of the "normal" population in that age span. Our evidence for this is discussed below. In spite of this limitation on our data, we believe it is useful to present our results now as the best estimates we have of the change in our measure of visual performance with age. Our data collection program on ages other than 20-30 is continuing, and any revisions in these estimates of the age-group populations will be reported when available.

Figs. 1 through 7 show individual log threshold contrast values for selected background luminances, separated by log unit intervals except for the highest luminance tested. The small dots represent the individual log threshold contrast values for each observer plotted at the appropriate age in years. The large X's represent the correct geometric means for each age group plotted at the average age for that group. The solid line represents the log threshold contrast obtained on 35 normal young adults age 20-30 by the forced-choice method of psychophysics for the indicated background luminance. The data used here are those summarized by Blackwell and Taylor[8] and represent the most up-to-date estimated means of these threshold values based on approximately 500,000 observations and considered to be final data by these authors. The individual data points on our scatter plots clearly show that individual differences are large, that they are larger for the older age groups, and that they become larger for all age groups as the background luminance is reduced below one fL (3.4 cd/m²). A glance at the X's shows that the average log threshold contrast increases with age at all

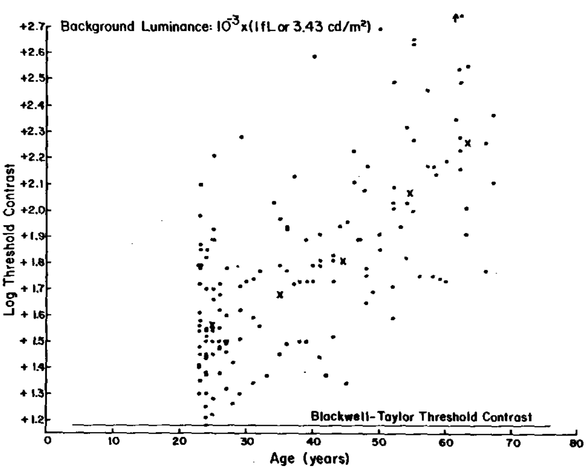

Figure 7. Scatter plot for background luminance: 10^{-3} x (1fL or 3.43 cd/m²).

background luminances, but that age groups 30-40 (average age 35), and 40-50 (average age 44.3) are approximately equal in visual performance at 500- and 100-fL background luminance. Age group 40-50 shows a gradual departure from the 30-40 performance level as background luminance decreases to our lowest level, 0.001 fL (0.003 cd/m^2), indicating lower visual performance potential for these observers.

All the individual data points except two, and all the average threshold contrast values lie well above the line representing the Blackwell-Taylor threshold contrast for each background luminance. This result was expected since the Blackwell-Taylor threshold contrasts were obtained by the forced-choice procedure. This psychophysical method has been shown by Blackwell[9] to yield substantially lower thresholds than any other method. In fact, most of the observers in experiments involving this method think they are seeing nothing at the threshold level. The method of adjustment which we used in this study is much more closely related to common-sense seeing as described by Blackwell,[1] and would be expected to give higher threshold contrasts even for those observers in the same age group, namely 20-30. This effect is most clearly demonstrated in Fig. 8. Here we have a direct comparison between the average threshold contrast curve obtained by our 68 normal observers in the 20-30 age group using our method of adjustment and the threshold contrast curve represented by the Blackwell-Taylor forced-choice data for the same age group. The *X*'s represent the means for our observers. The solid line represents the Blackwell-Taylor threshold curve. The dashed line represents the Blackwell-Taylor threshold curve moved upwards on the task contrast scale to best fit the data. As can be seen, the curve fits the data exactly when each value of task contrast is multiplied by a factor of 2.51. This means that there is a sizeable difference between the common-sense criterion of seeing represented by our method of adjustment and the laboratory forced-choice procedure. Yet the functional relationship between task contrast and background luminance is the same when studied with the two methods except for a constant of

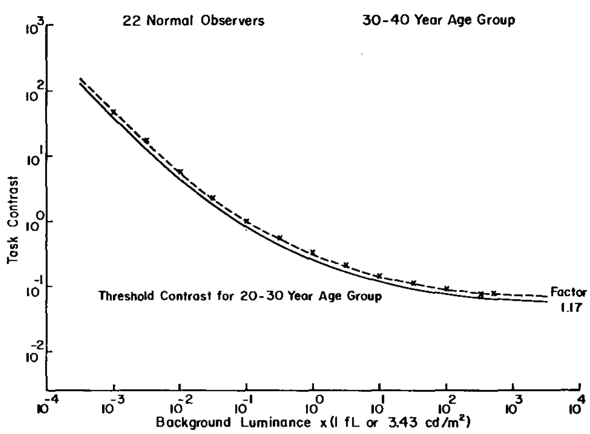

Figure 9. Comparison of the threshold contrast data for age group 30-40 years with the curve for age group 20-30 years using the psychophysical method of adjustment.

proportionality. We will delay relating the factor of 2.51 to a "common-sense seeing factor" until a subsequent section of this report.

In view of this difference between the method of adjustment and forced-choice data, we may evaluate the loss in visual performance related to age most simply by using our own method of adjustment data for the 20-30 age group as a baseline of comparison for the data obtained by the same method with older observers, as has been done in Figs. 9-12. In each of these figures, we have presented the method of adjustment data for our 68 observers age 20-30 as a solid curve. The *X*'s represent the average threshold contrasts for the age group indicated on the graph. The dashed line represents the 20-30 threshold curve translated upward to make the best fit to the threshold contrasts for background luminances above 0.29 fL (1.0 cd/m^2), that is, those luminances considered important in the specification of interior illumination. In so far as the data points can be fitted by the standard curve translated

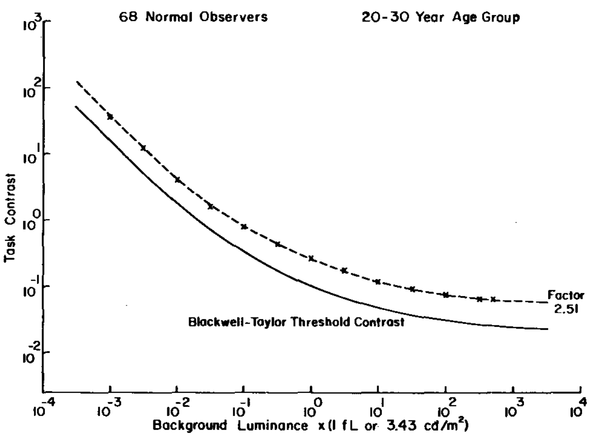

Figure 8. Comparison of the threshold contrast data obtained by the psychophysical method of adjustment with the curve obtained by the forced choice procedure for the same age group.

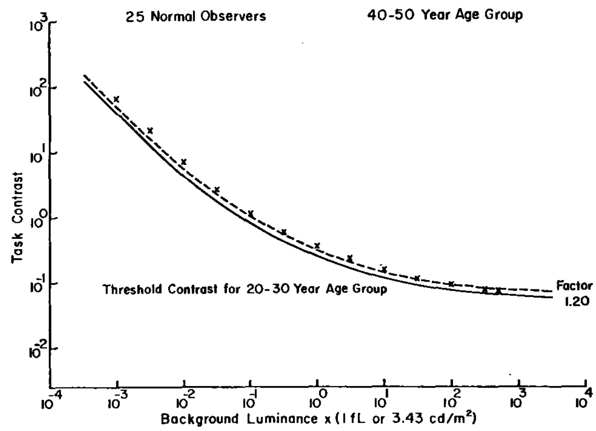

Figure 10. Comparison of the threshold contrast data for age group 40-50 years with the curve for age group 20-30 years using the psychophysical method of adjustment.

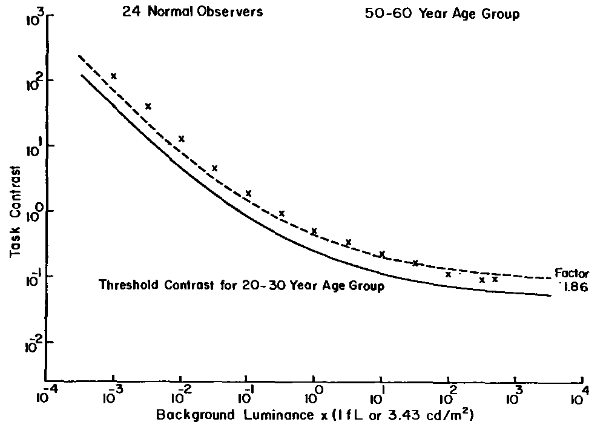

Figure 11. Comparison of the threshold contrast data for age group 50-60 years with the curve for age group 20-30 years using the psychophysical method of adjustment.

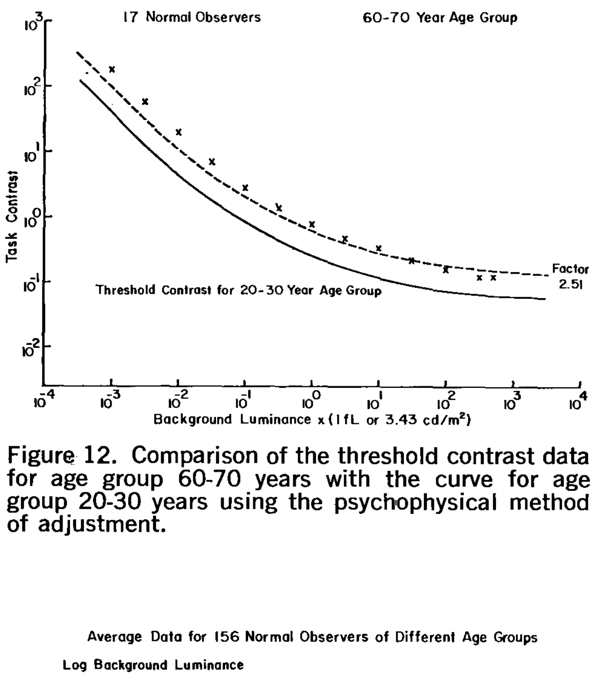

Figure 12. Comparison of the threshold contrast data for age group 60-70 years with the curve for age group 20-30 years using the psychophysical method of adjustment.

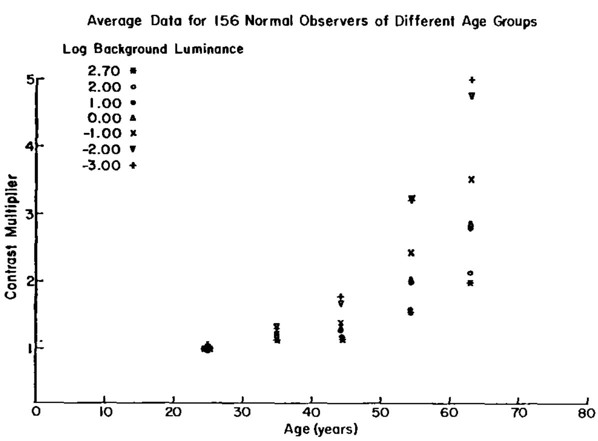

Figure 13. Contrast multipliers required to allow for differences in visual performance for different age groups at selected background luminances.

upward, to that extent can the effect of age be described by a simple multiplicative factor applied to the standard method of adjustment data for normal young adults. Indeed, in Fig. 9 we see that the data for our 22 normal observers in the 30-40 year age group are well fit by simply multiplying the 20-30 group standard by a factor of 1.17, meaning that these observers of age 30-40 require 1.17 times the contrast to see as well as the 20-30 year-olds at the same luminance level. Fig. 10 shows the same comparison for our 25 observers age 40-50. Here the factor is 1.20. The curve fits the data well except at the lowest background luminances which are of no interest in the specification of interior illumination levels. Fig. 11 shows a factor of 1.86 for the 24 observers age 50-60, but here we see a definite change in the shape of the curve as compared to the 20-30 age group, although this is most pronounced at the lower luminances and may still be close enough to the same shape above 0.29 fL to allow us to use a single multiplicative factor for engineering purposes. However, the data for our 17 normal observers in the 60-70 age group in Fig. 12 definitely are not at all well fit by the standard curve. The best fit produces a result showing that these observers require 2.51 times the contrast to see as well as the 20-30 year-olds at levels of interior illumination. However, if the complete lack of parallelism of the two curves is verified when more observers are studied, it will probably not be possible to correct for the effect of this much difference in age by a single multiplication factor.

Fig. 13 presents samples of these data in another way. Here are plotted values of the multipliers required to allow for differences in visual performance related to age at selected background luminances. As was apparent both from the scatter plots of Figs. 1 to 7 and the curves of Figs. 9 to 12, the contrast multiplier increases with age and increases more the lower the level of background luminance. The fact that the data points in Fig. 13 do not cluster together into a single curve reveals the dependence of the contrast multiplier upon luminance, and raises a question as to the validity of the contrast multiplier concept we have used for some years, used also more recently by Guth and McNelis.[10] Of course, the failure of the data points to fit the dashed curves in Figs. 10 to 12 illustrates this in another way. Fig. 13 shows clearly that the contrast multiplier concept is reasonably valid for observers of age less than 60 years, for background luminances above 0.1 fL (0.34 cd/m^2). Outside these limits, the concept is questionable.

Fig. 14 presents values of the contrast multiplier derived from the method of curve fitting shown in the dashed-curve constructions of Figs. 9 to 12. It will be recalled that the dashed curves were fitted to the data points at luminances above 0.29 fL (1.0 cd/m^2), so that these contrast multipliers represent average values for all luminances equal to 0.29 fL and above. (These values agree generally with values obtained by averaging appropriate data presented in Fig. 13 as they should.) We see that the contrast multiplier varies rather slowly with age up to age 45 years, then shows a very rapid increase with further increases in age.

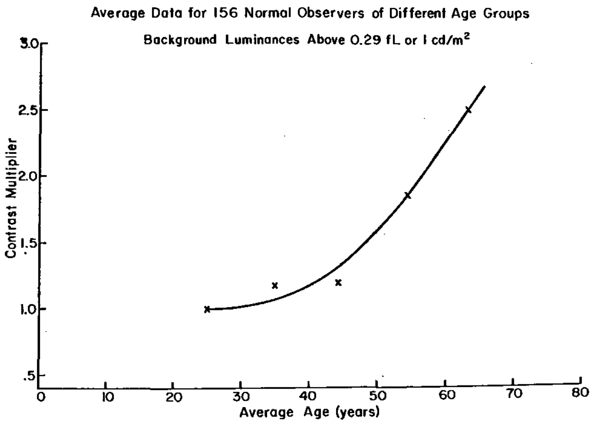

Figure 14. Contrast multipliers required to fit the 20-30 year age group threshold contrast curve to that for other age groups at background luminances of interest in illumination specification.

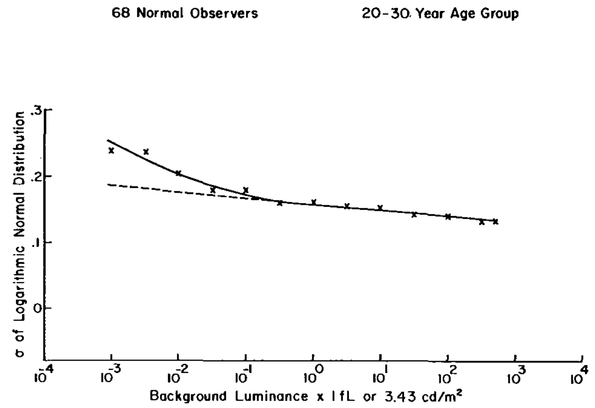

Figure 15. Variability among observers of age group 20-30 years as a function of background luminance.

To this point, we have considered only the average visual performance data for observers in each of our age groups. We may examine the data for individual members of each age group in order to estimate variations to be expected in the population of observers of various ages. The procedure may be described as follows: At each luminance, consider the mean value of log threshold contrast plotted in earlier figures as an estimated mean. Compute the value of the difference between the log contrast obtained by a given observer at a given luminance and the estimated mean for his age group, at that luminance. Tally a cumulative frequency distribution of these values of Δ Log Contrast. Plot the cumulative probabilities of occurrence as a function of Δ Log *C* on "probit paper" which converts a normal frequency function to a straight line. Fit a straight line to the data by eye. Read off the mean value of Δ Log *C* corresponding to a probability of 50 per cent. Compute the value of the standard deviation, σ_{log}, from the slope of the straight line.

The value of Δ Log *C* corresponding to a probability of 50 per cent will approach zero, but will usually depart by .01 to .03 log units. This signifies that the original estimated mean obtained by averaging values of log threshold contrast is not the best estimate of the population mean for that luminance, but requires correction by the value of Δ Log *C* obtained. Once this correction has been made in the absolute value of mean Log *C*, then the cumulative frequency data and the curve fitted through them may be considered shifted on the probit paper so that the curve passes through Δ Log $C = 0$ at 50 per cent probability. Then antilogs of the values of Δ Log *C* represent contrast multipliers for different proportions of the population.

As noted earlier, this process was followed in deriving the values of corrected mean Log *C* plotted in Figs. 1 to 7 and 9 to 12. In these cases, the cumulative frequency distributions represented combined frequency data obtained at all 13 luminance levels for which data exist. Thus, all data points have been corrected with a single constant and the form of the curve relating log threshold contrast to log background luminance has not been altered by the correction process.

We have not assumed that the extent of variation among different observers in a given age group is independent of luminance since, as noted in the discussion of Figs. 1 to 7, there appears to be greater spread among observers in a given age group the lower the luminance. We have analyzed data for the 20-30 year age group to determine the quantitative character of the dependence of observer variability upon luminance. Since there were 68 observers in this group, we could analyze the variability data separately at each of the 13 levels of luminance, fitting a probit line to each by the method described above. The results of this analysis are shown in Fig. 15. As can be seen, the value of σ_{log} increases as the luminance decreases and although this happens over the whole range of luminances, it happens much more rapidly at luminances below 0.1 fL (0.34 cd/m²). The dotted line on the graph indicates the curve which would have resulted had there been a continuation of the rate of change of σ_{log} with decrease in luminance found at the higher luminances. Indeed, this is a precise way of showing what was obvious in

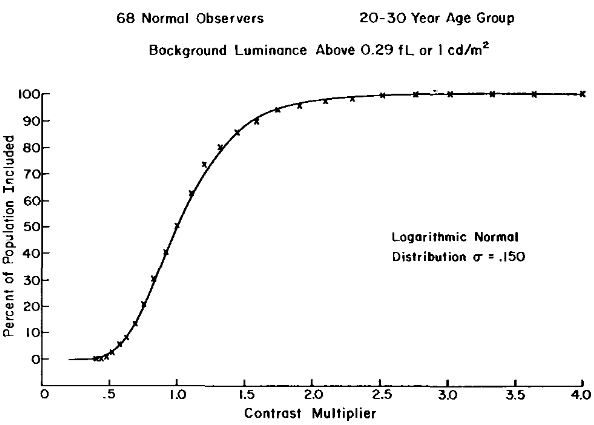

Figure 16. Proportion of the population of observers in age group 20-30 years requiring given contrast multipliers to provide equal visual performance to the average of their age group.

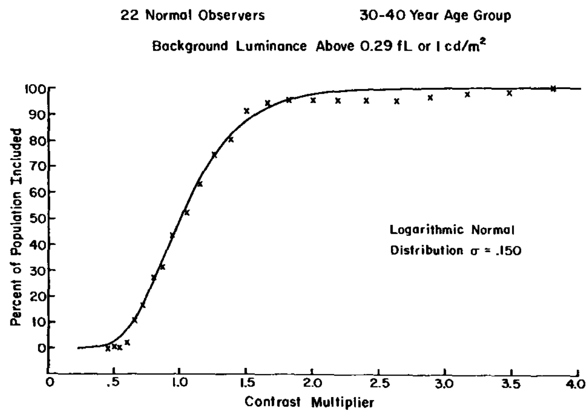

Figure 17. Proportion of the population of observers in age group 30-40 years requiring given contrast multipliers to provide equal visual performance to the average of their age group.

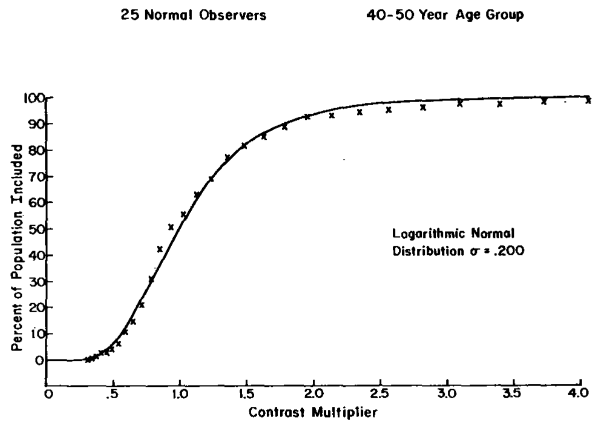

Figure 18. Proportion of the population of observers in age group 40-50 years requiring given contrast multipliers to provide equal visual performance to the average of their age group.

the scatter plots of the individual data in Figs. 1 through 7.

We conclude that our analysis is most simple and direct when we combine the data obtained at the higher luminances, at which σ_{log} does not change so rapidly with luminance. For consistency with the method used to construct the dashed curves in Figs. 9 to 12, we have pooled data on observer variability for luminances equal to 0.29 (1.0 cd/m^2) fL and above. The result is a single cumulative frequency distribution for each age group, represented by a straight line on the probit plot. We may derive numerical values for this best-fitting cumulative frequency distribution either by reading values from the probit graph or by computing values from published tables and the value of σ_{log} corresponding to the probit line fitted through the data. In either case, we plot the cumulative probability as a function of the antilog of Δ Log C and identify this quantity as a contrast multiplier. Figs. 16 to 20 result from this process. Each shows the cumulative probability as a function of the contrast multiplier for observers in a given age group. The X's are the cumulative probabilities computed from the data; the solid curves are the normal frequency functions represented by the probit line fitted to the data points. Since the probability data were found to be described by normal frequency functions in terms of Δ Log C, the solid curves in Figs. 16 to 20 are skewed on a linear scale of the contrast multiplier. Data points fit the smooth curves reasonably well, especially for the age groups having the largest numbers of observers in the samples studied.

The meaning of the curves of Figs. 16 to 20 may be described as follows: use of average contrast data for observers of a given age group provides exactly 50 per cent of the observers in this group with the level of visual performance defined by the task required of the observers. Contrast multipliers may be used to compute the levels of task contrast needed to provide different proportions of the population of observers in a given

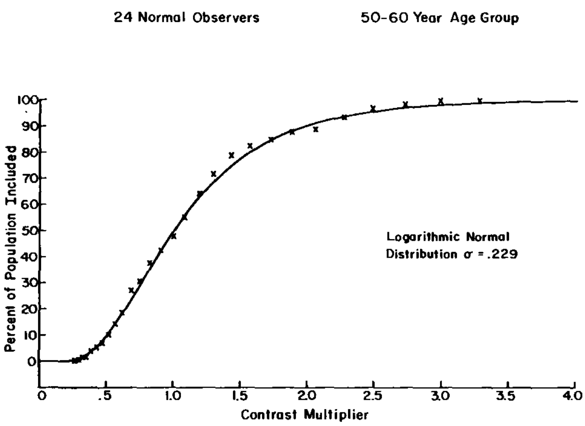

Figure 19. Proportion of the population of observers in age group 50-60 years requiring given contrast multipliers to provide equal visual performance to the average of their age group.

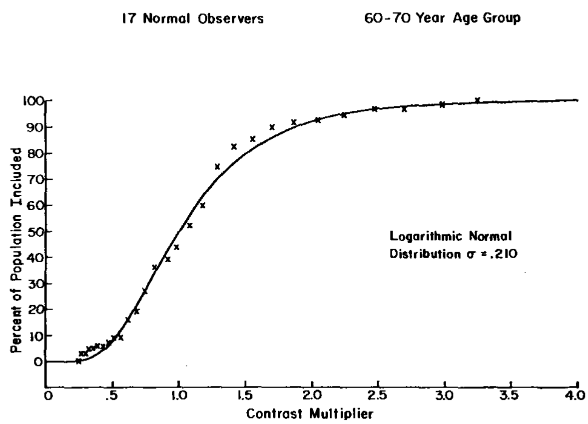

Figure 20. Proportion of the population of observers in age group 60-70 years requiring given contrast multipliers to provide equal visual performance to the average of their age group.

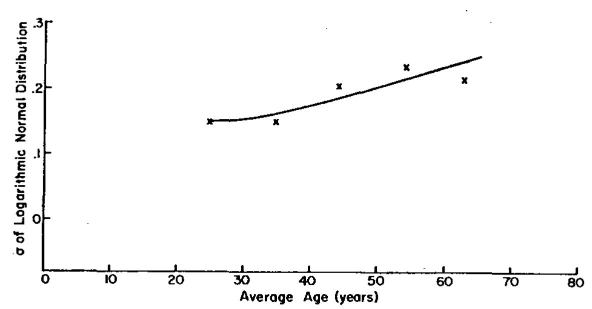

Figure 21. Observer variability as a function of age. Sigmas of the log normal distributions have been corrected for sample size to provide an estimate of the population of a given age group.

age range with this standard level of visual performance. Contrast multipliers less than one provide this level of visual performance to less than 50 per cent of the observers in the age group; contrast multipliers greater than one provide the performance level to more than 50 per cent of the observers. A contrast multiplier may be selected to provide the standard level of visual performance to as few or as many observers in a given age group as desired by direct reference to the solid curves in the figures.

Fig. 21 presents values of σ_{log} as a function of average age. These values represent estimates for the entire population of a given age group derived from our data on a sample of observers from the relationship:

$$\sigma_{log}' = \sigma_{log}\sqrt{N/N-1} \qquad (1)$$

where σ_{log} is the obtained value;
N is the number of observers in the sample; and
σ_{log}' is the estimate of the population value.

The data points in Fig. 21 show in general the effect noticed in the scatter plots of Figs. 1 to 7, namely the increase in observer variability as a function of age. The decrease in σ_{log} for the age group 60-70 is unexpected. A possible explanation is that by this age many subclinical ocular defects which may be causing the variability in the younger age groups have become manifest. Since we have eliminated these observers from our sample, we have accordingly reduced the variability. Our future study of the underlying causes of the decrease in contrast sensitivity with age will help to elucidate this point.

It is possible to use the smooth curve of Fig. 14 representing the value of the contrast multiplier as a function of age and the smooth curve of Fig. 21 representing the value of the σ_{log} as a function of age to define contrast multipliers for different proportions of the population of observers of various ages just as Guth and McNelis[10] have done. These contrast multipliers are presented in Table I for average ages varying from 20 to 65 years. The multipliers represent levels of background luminance equal to 0.29 fL (1.0 cd/m²) and above. Use of these values to describe our data is at best an approximation which may be useful for engineering purposes. On the basis of our earlier analyses, the approximation appears reasonably valid for observers younger than 60 years of age.

THE SUPPLEMENTARY STUDY*

Fig. 8 has presented a comparison between data obtained with our method of adjustment and data obtained by Blackwell and Taylor[8] with the forced-choice procedure, all observers being in the 20-30 year age group. The target was a 4-minute luminous disc, presented for one-fifth-second exposures. As noted above, comparison between these two sets of data provides a measure of the factor relating common-sense seeing to laboratory forced-choice visual performance. As shown in Fig. 8, this factor is 2.51, representing the contrast multiplier required to correct the differences between the two procedures. Blackwell[1] reported a factor of 2.40 for the contrast multiplier required to convert from threshold contrast values obtained with the laboratory forced-choice procedure to contrast thresholds obtained by naive observers using a "Yes-No" response. These two factors are quite similar. However, before conclud-

*The authors are greatly indebted to Mrs. Kathryn Heft who was responsible for collection and preliminary analysis of the data of this study.

Table I—Contrast Multipliers for Different Portions of the Normal Population

Average Age (years)	Percentage of Population Included					
	50%	60%	70%	80%	90%	95%
20	1.00	1.09	1.20	1.34	1.56	1.76
25	1.00	1.09	1.20	1.34	1.56	1.76
30	1.02	1.12	1.23	1.37	1.60	1.82
35	1.07	1.18	1.30	1.47	1.73	1.98
40	1.17	1.30	1.44	1.64	1.96	2.27
45	1.34	1.50	1.68	1.93	2.34	2.74
50	1.58	1.78	2.03	2.35	2.88	3.42
55	1.90	2.16	2.48	2.91	3.64	4.37
60	2.28	2.62	3.03	3.59	4.57	5.56
65	2.66	3.09	3.61	4.33	5.59	6.92

ing that this confirms the original value let us examine the precise comparisons involved.

In the original experiments, 70 observers in the 20-30 year age group were required to detect the presence of an 18.5 minute luminous disc presented for 0.072 second seven degrees from the line-of-sight at a background luminance of 4.71 fL (16.1 cd/m²). Single exposures were used. Initially, naive observers were required to respond "Yes" when they saw the target and "No" when they didn't. The threshold was taken as the value of target contrast at which the Yes response occurred 50 per cent of the time. These same observers were subsequently trained in the laboratory forced-choice method and the values of target contrast determined at which they made correct forced-choice responses 50 per cent of the time after allowance for chance. The commonsense factor of 2.40 was the average ratio of the first contrast divided by the second. Observers were the same, and in each case observers had to respond to single target presentations.

In contrast, the comparison in Fig. 8 involves two populations of observers in the same age group, 35 of whom used the forced-choice procedure and 68 of whom used the method of adjustment. Single one-fifth-second presentations were used with the forced-choice procedure which represents a variant of the classical method of constant stimulus, but trains of one-fifth-second presentations were involved with the method of adjustment procedure. In the latter procedure observers did not use any kind of verbal response which could be expressed as a percentage of the correct response.

Since these differences both in observer population and experimental conditions might affect the factor relating the two contrast functions of luminance, a supplementary experiment was designed to permit us to compare the two estimates of the common sense factor more directly. A group of 38 normal observers in the 20-30 year age group was used under each of two experimental conditions. The first involved our method of adjustment, with trains of one-fifth-second exposures precisely as in the main study. The second was a classical method of constant stimulus involving single one-fifth-second exposures, with the observers required to make a "Yes" response when they saw the target and to report "No" when they did not. This procedure duplicated the procedure in which naive observers responded "Yes" or "No" to the presence of the target in Blackwell's[1] experiment. The target was the 4-minute disc, presented at a background luminance of 100 fL (343 cd/m²). Unlike all previous experiments discussed here, viewing was monocular.

The mean log threshold contrast obtained by the method of adjustment was computed as before by averaging individual values of log threshold contrast for the 38 observers to obtain an estimated mean, then correcting the estimate based upon an analysis of the frequency distribution of individual values. The corrected mean log threshold contrast was —1.10. This is to be compared with a value of —1.13 obtained with the 68 normal observers in the same age group in the main study. The mean threshold contrast was thus seven per cent higher in the present study than in the main study, a small difference probably due to the use of monocular rather than binocular vision in the present study.

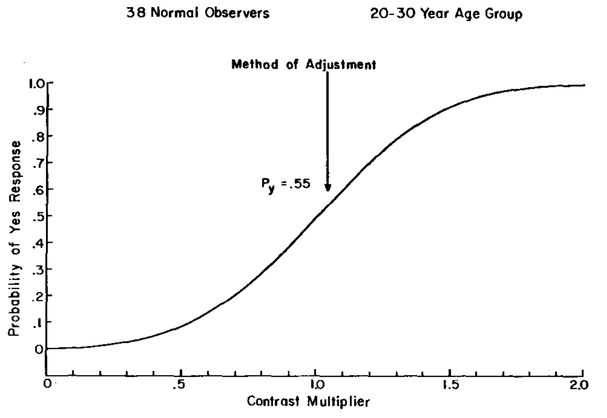

Figure 22. Probability of "Yes" responses in the psychophysical method of constant stimulus for different contrast multipliers when 50% "Yes" responses occur at unity.

Data from the method of constant stimulus were first subjected to the usual probit analysis in terms of a linear scale of target contrast, with a value of the median threshold, M, and the σ of the ogive given for each of the 38 observers. The estimated mean log threshold contrast for the 38 observers was computed as before by averaging individual values of log threshold contrast, and then was corrected on the basis of a frequency distribution analysis of the individual values. The corrected mean log threshold contrast was —1.12. This signifies that the mean threshold contrast obtained by the method of adjustment was 4.8 per cent higher than the mean threshold obtained by the method of constant stimulus.

This comparison allows us to estimate the commonsense factor to have been expected had our 68 observers who used the method of adjustment used instead the method of constant stimulus involving naive "Yes-No" responses. The factor separating their method of constant stimulus data from the Blackwell-Taylor forced-choice data is estimated to be $2.51 \div 1.048 = 2.39$. This factor is based upon a comparison equivalent to that made in the original study with the 70 observers in which the factor was found to be 2.40. Agreement is more than satisfactory.

It is of interest to evaluate the method of adjustment criterion of common-sense seeing for trains of target presentations in terms of the equivalent percentage of "Yes" responses for single presentations. To do so, we compute the average probability curve obtained by the 38 observers with the method of constant stimulus. Probit analysis yields values of the quantity σ/M which measures the steepness of the probability curve. The average value was 0.365. This average probability curve is shown in Fig. 22 in terms of the contrast multiplier required to reach different percentages of "Yes" responses with 50 per cent "Yes" responses occurring at a value of unity. The contrast multiplier of 1.048 obtained with the method of adjustment data corresponds to 55 per cent "Yes" responses to single target

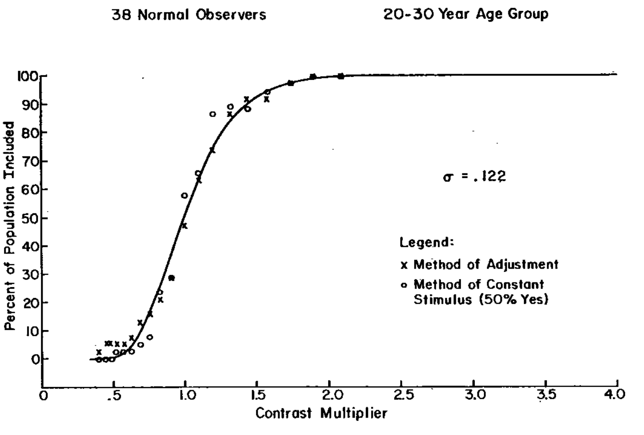

Figure 23. Proportion of the population of age group 20-30 years requiring given contrast multipliers to provide equal visual performance to the average of their age group. Comparison of the data obtained by psychophysical methods of adjustment and constant stimuli.

presentations. It is this level of naive "Yes" responses to single target presentations which is represented by the method of adjustment criterion of common-sense seeing.

The analyses of individual variations in the mean threshold values performed on the data obtained with the two methods permit us to plot Fig. 23. This figure represents the cumulative frequency data for the 38 observers obtained with each method. The solid curve is the normal frequency function fitted individually to each set of data on the probit graphs, plotted as in Figs. 16-20 on a linear scale of the contrast multiplier. The data obtained with each method fit the same skewed ogive as well as they fit any smooth curve. This signifies that the degree of individual variation in the threshold contrast is the same for naive observers whether they use our method of adjustment or the method of constant stimulus involving naive "Yes" responses. This result encourages us in continued use of the much simpler and speedier method of adjustment when studying the visual performance potential of large numbers of observers.

CONCLUSIONS

In conclusion, we can say that we have presented here data on the visual performance potential of 156 "normal" observers from age 23 to 68 years, which can be regarded as an approximate assessment of the normal population of this age range. The data show clearly the large differences in visual performance capability both among individual observers of the same age and between the averages of different age groups. In using these data for evaluating the adequacy of illumination recommendations in codes and standard practices, it should be remembered that these observers represent the optima of the age groups studied and not the average of the population as a whole, since we have eliminated all observers with discernible ocular defects of a clinical nature and those with visual acuity less than 20/30. Further research is being conducted to understand the effects of such defects on visual performance potential. Thus, our data should be regarded as a conservative assessment of the visual performance potential of the general population from 20 to 70 years of age.

It should be emphasized that this is a study of visual performance *potential* only. This is a measure of the level of visual performance possible taking account of task visibility alone. It is measured for reference lighting conditions; namely, diffuse illumination of the task and uniform luminance over the entire field. The observer has fixation points to show him exactly where to look and hears a click which tells him exactly when the 1/5-second exposure will appear. To apply these results to the specification of illumination levels, it will be necessary to study visual performance *capability* as a function of age. This is a measure of visual performance which includes both task visibility and the conditions of observation and response required by the task. Clearly, visual performance capability includes the oculomotor adjustment functions of accommodation, convergence, and fixation and it is by no means certain that these functions are unaffected by age.

The results of our main study taken in conjunction with the results of a special supplementary experiment provide a new assessment of the factor for common-sense seeing, a contrast multiplier used to convert from laboratory forced-choice threshold data to thresholds corresponding to more ordinary criteria of just barely seeing. The value derived from the present work is 2.39, which is in excellent agreement with the value of 2.40 reported by Blackwell[1] in 1959.

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