

INDIVIDUAL DIFFERENCES IN CONTRAST SENSITIVITY

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Mrs. Blackwell: The data I wish to present to you today were obtained in a study of contrast sensitivity as a function of luminance for 156 observers of ages varying from 20 to 70. These data were reported in *JIES*, Vol. 1, No. 1, Oct. 1971, in an article by O.M. and H.R. Blackwell. The details can be found there. We obtained contrast sensitivity curves on 156 observers for uniform background luminances from 0.001 to 500 fL. (or .003 to 1710 cd/m²) for a 4-minute disc, presented in a continuous train of 1/5-sec. exposures in the center of four fixation lights adjustable in luminance. Each observer was required to adjust the luminance of the 4-minute disc until he could just barely tell that something was there—a detection threshold.

It should be emphasized that we selected our observers to be so-called "normal." This is here defined as meaning that they were free of any ocular defects discernible under the usual clinical examination and that they had a visual acuity corrected or uncorrected of at least 20/30. We selected our observers in this way with the idea of adding in the effects of abnormalities in proportion to medical statistics of their occurrence in a relevant population at such time as our studies have elucidated their effects. We found that this method of selection made it more and more difficult to find observers as age increased. This is another way of saying that our older age groups do not represent the "average" of their age group but more likely the optimum of their age group. We arbitrarily divided our observers into 10-year age spans including all the observers we had studied up to a particular time. For this reason, the number (N) for the different groups is not the same. This should be kept in mind in evaluating the data.

With this as preamble then, I will show you the data and show their use when applied to

the lighting standards problem. Figure 1 shows the contrast sensitivity for 68 "normal" 20–30 year old observers for uniform background luminances of 0.001 to 500 fL. (.003 to 1710 cd/m²) for a 4-minute disc presented in 1/5-sec. exposures. This curve has been adopted as the standard visibility reference function in CIE Report No. 19. It serves as an arbitrary reference base to which to compare the contrast sensitivity curves of the succeeding age groups. Figure 2 shows the contrast sensitivity function of luminance for 22 observers of age 30–40. The x's are the actual data points. The solid curve shows the data for the 20–30 year old reference population. The dotted curve is this same visibility reference function translated upward on the contrast scale to make the best fit for background luminances above 0.29 fL. or 1.0 cd/m²; that is, those luminances considered important in the specification of interior illumination.

In so far as the data can be fitted by the reference curve translated upward on the contrast axis, to that extent can the effect of increasing age be described by a simple multiplicative factor applied to the reference data from the 20–30 year-olds. In Figure 2 we see that the data for the 30–40 year-olds are well fit by simply multiplying the reference data by a factor of 1.17, meaning that the average 30–40 year-old needs 1.17 times the contrast to see as well as the 20–30 year-old average at the same luminance level. Figure 3 shows the comparison for age group 40–50. Here the contrast sensitivity multiplier is 1.20. The curve fits the data well except at the lowest luminances which are not relevant to interior illumination levels. Figure 4 shows a factor of 1.86 for age group 50–60, but here we see a definite change in the shape of the curve, although this is most pronounced at the lower luminances and may still be close enough to the same shape above 0.29 fL. (1 cd/m²) to

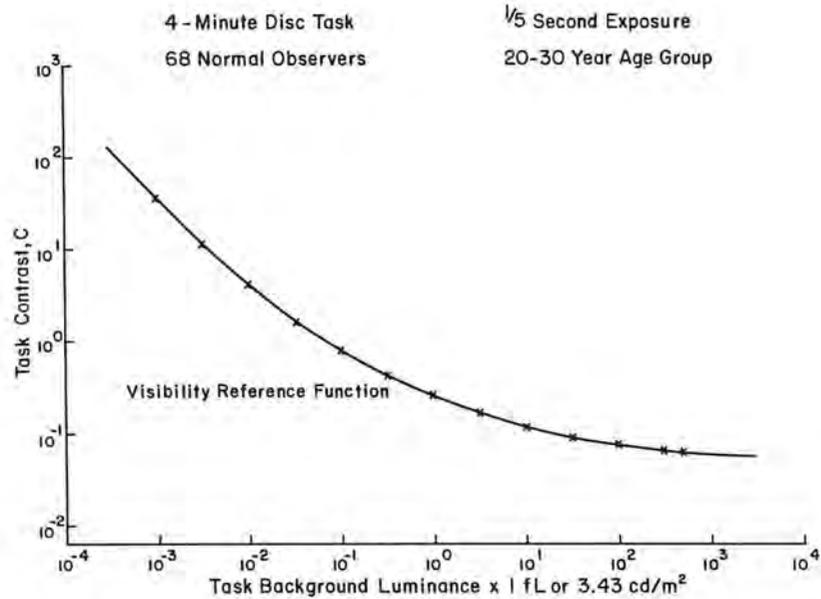


FIGURE 1.—Visibility reference function (20-30 year age group).

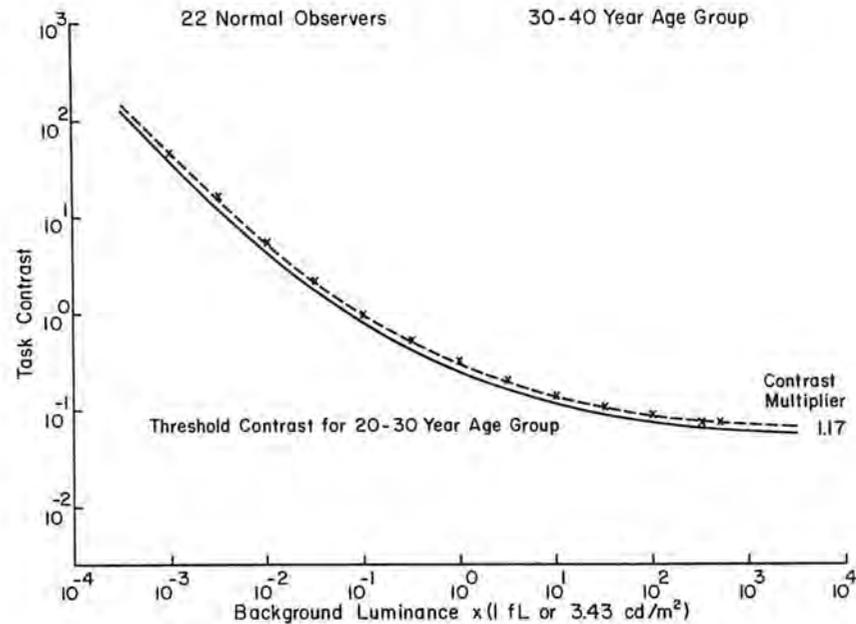


FIGURE 2.—Contrast sensitivity function for the 30-40 year age group compared to that of the 20-30 year age group.

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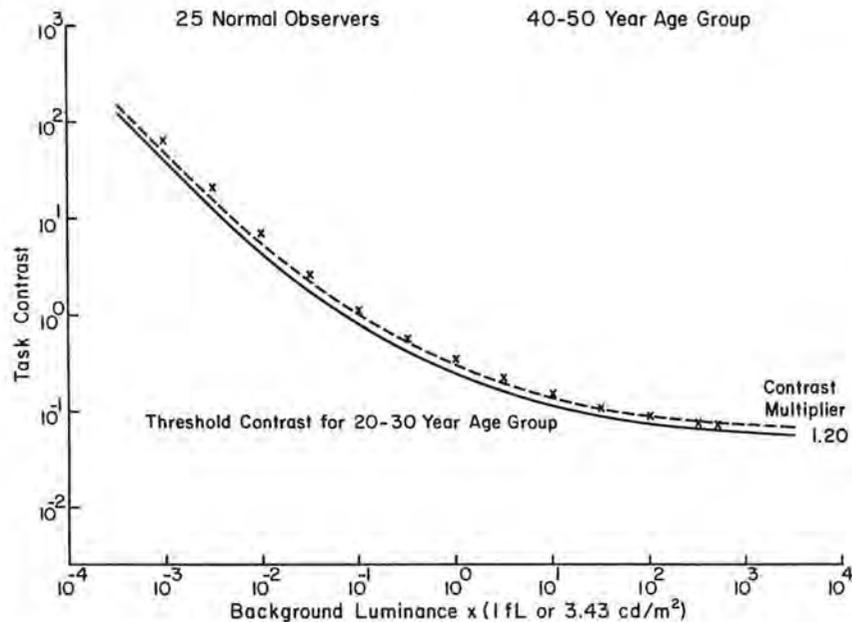


FIGURE 3.—Contrast sensitivity function for the 40-50 year age group compared to that of the 20-30 year age group.

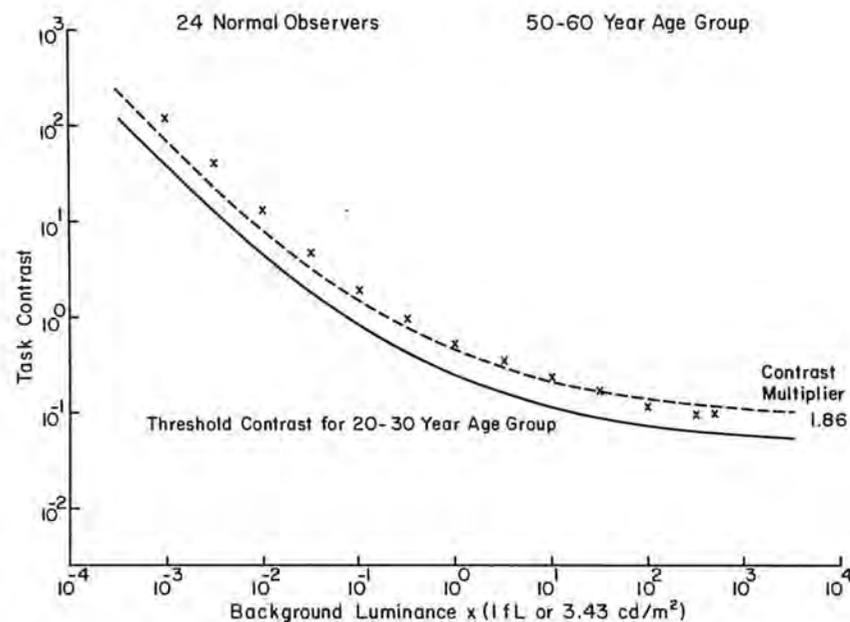


FIGURE 4.—Contrast sensitivity function for the 50-60 year age group compared to that of the 20-30 year age group.

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allow us to use a single multiplicative factor for engineering purposes. Figure 5 shows the data for our 60–70 year-olds. Here the data are definitely not well fit by the reference curve. The best fit yields 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. Figure 6 presents values of the contrast multiplier derived from the method of curve fitting shown in the dashed curve constructions in the preceding figures. These contrast multipliers represent average values for all luminances equal to or above 0.29 fL. (1 cd/m²). We see that the contrast multiplier varies rather slowly with age up to about 45 years and then shows a rapid increase with further increases in age.

To this point we have considered only average contrast sensitivity data for observers in each of our age groups. We may examine the data for individual members of each group in order to estimate variations to be expected in the population of observers of various ages. Again, we have used only the data for 0.29 fL. (1 cd/m²) and above. Figure 7 shows the proportion of observers in the 20–30 year-old age group requiring a given contrast multiplier to achieve equal contrast sensitivity to the average of the age group. This and the following graphs (Figures 7-11) show the cumulative probability as a function of contrast multiplier for observers in a given age group. The \times '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 found to be described by normal frequency functions in terms of $\Delta \log C$, the solid curve in this and the following graphs is skewed on a linear scale of contrast multiplier. The meaning of the figure can be described as follows: use of average contrast data for observers of a given age group provides exactly 50% of the observers in this group with the level of contrast discrimination defined by the task required of them, in this case, just barely detecting the 4-minute disc presented in 1/5-sec. exposures. Contrast multipliers may be used to compute the level of task contrast needed to provide different proportions of the population of observers in a given age range with this standard level of contrast sensitivity. Contrast multipliers less than 1 provide less than this level to less than 50% of the popula-

tion, whereas a multiplier of more than 1 provides the standard contrast sensitivity to more than 50% of the observers. Figure 8 shows the proportion of observers of age 30–40 requiring given contrast multipliers to provide equal contrast sensitivity to the average of their age group. Figure 9 shows the same for age 40–50. Figure 10 shows the proportions for age group 50–60, and Figure 11 shows the distribution for the 60–70 year age group.

Figure 12 shows 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. Here we see in general an increase in variability as a function of age except for an unexpected decrease in σ log for the age group 60–70. A possible explanation for this may be that, by this age, many of the subclinical optical defects which may be causing variability in the younger groups have become manifest. Since we have eliminated these observers from our sample, we would accordingly have reduced the variability. We have used the smooth curve representing the value of the contrast multiplier as a function of age and the smooth curve in this figure representing the value of σ log as a function of age to define contrast multipliers for different proportions of the population of observers of various ages.

Figure 13 shows the importance of these individual differences in contrast sensitivity in the setting of our interpretation of standards of illumination. Figure 13 returns again to the visibility reference function; i.e., the average contrast sensitivity as a function of luminance for the 20–30 year age group for the visibility reference task, a 4-minute disc exposed for 1/5 sec. This is represented by the solid line. The bell-shaped curve, which should be in the third dimension, shows the distribution of contrast threshold curves among different individuals in this reference population. The dotted lines show the curves for the least and most sensitive individuals. The significance of these individual differences becomes obvious when one selects some particular criterion visibility level such as VL8 which is the upper solid curve in the figure and the one incorporated into the present U.S. lighting standards. This visibility level defines the ratio of the values on the two solid lines in the graph, which is the distance between them as plotted here. The

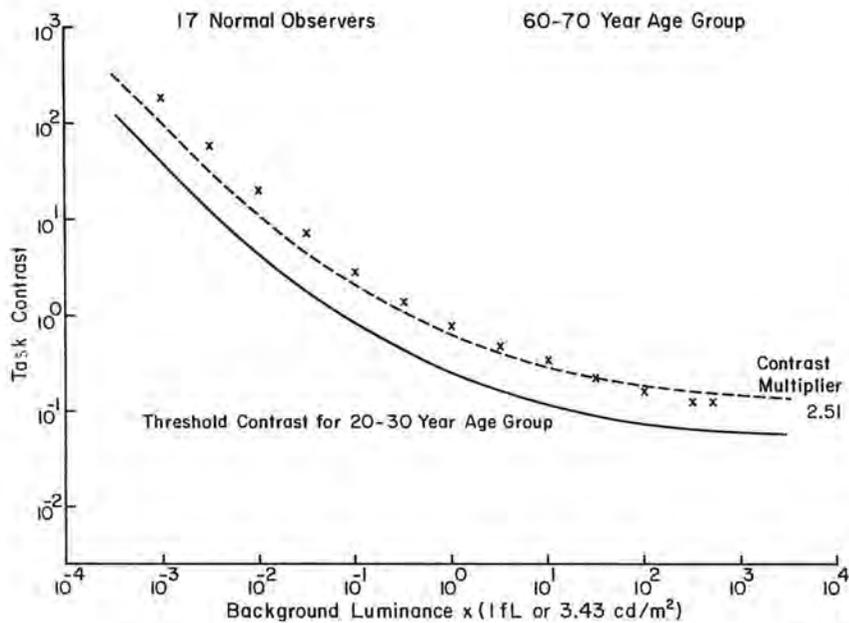


FIGURE 5.—Contrast sensitivity function for the 60-70 year age group compared to that of the 20-30 year age group.

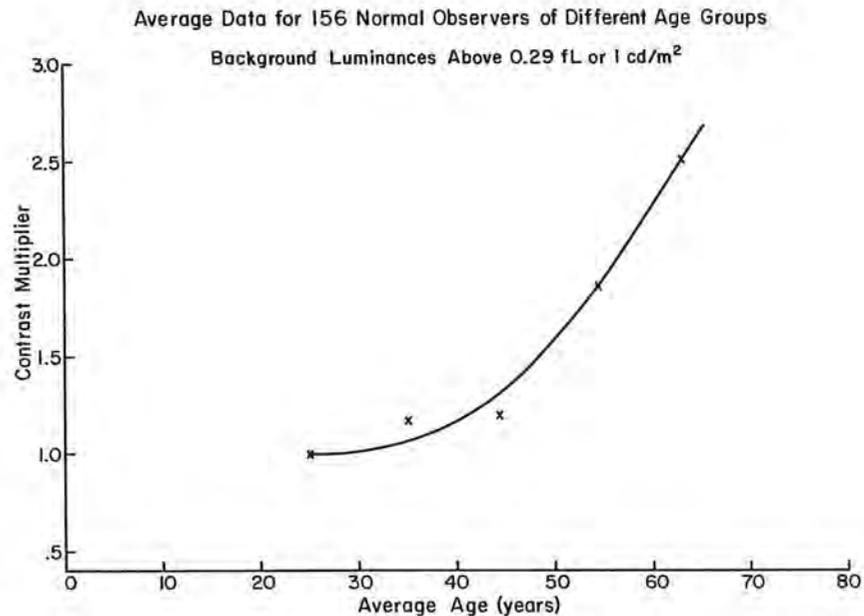


FIGURE 6.—Contrast multipliers required to fit the 20-30 year age group threshold contrast curve to that of other age groups at background luminances of interest in illumination specifications.

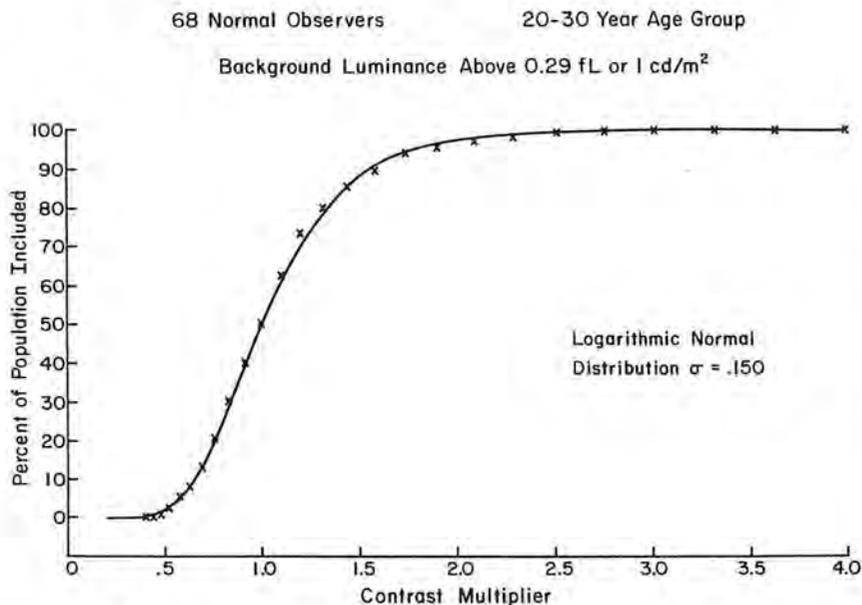


FIGURE 7.—Contrast multiplier required to achieve average contrast sensitivity of group (20-30 year age group).

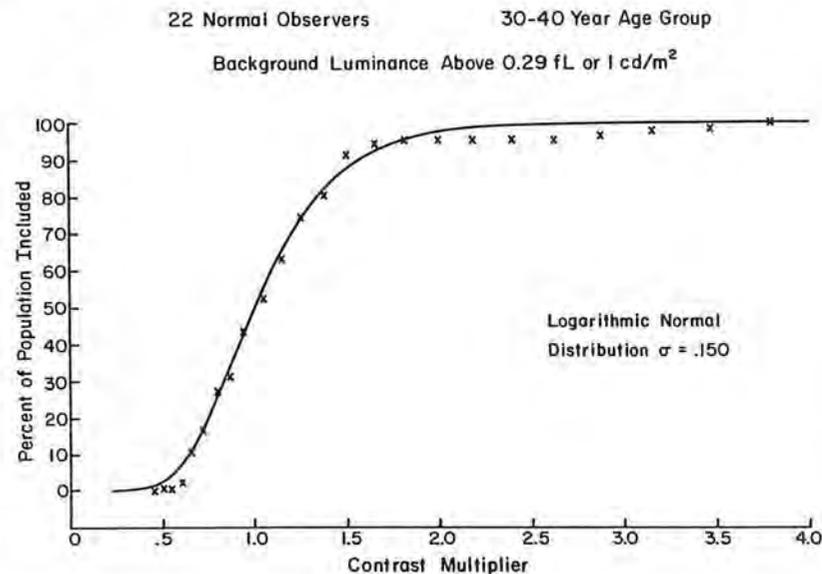
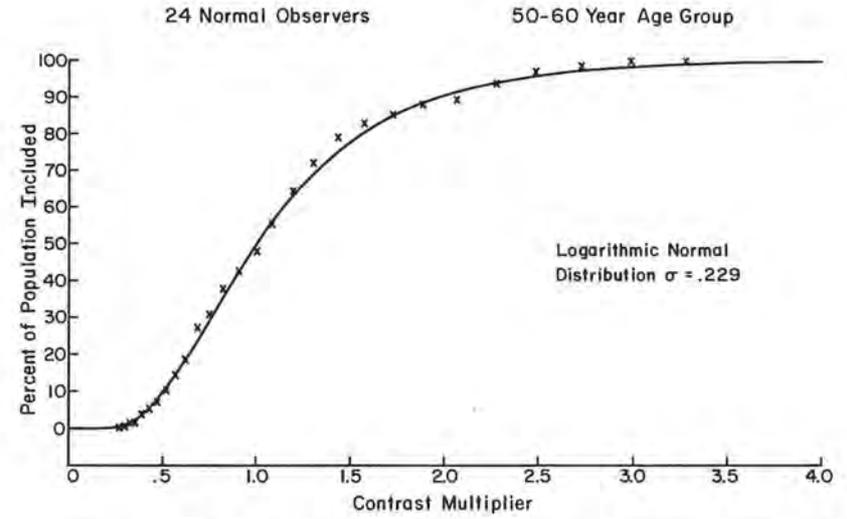
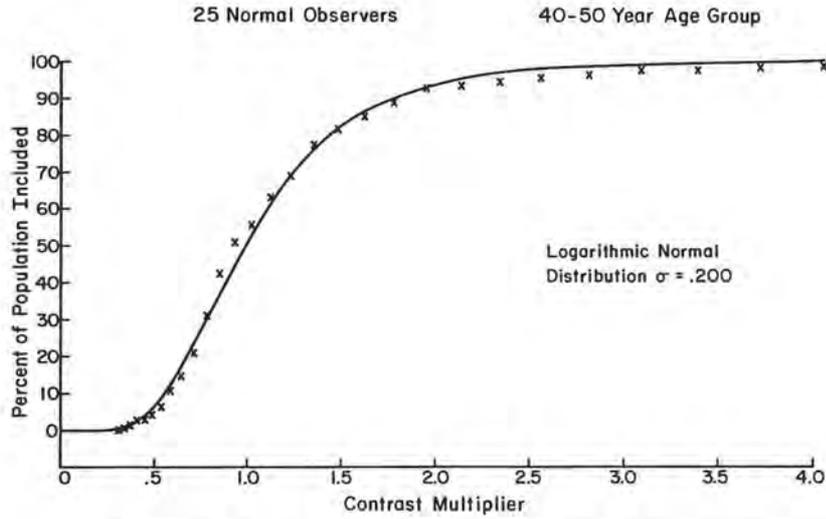


FIGURE 8.—Contrast multiplier required to achieve average contrast sensitivity of group (30-40 year age group).



99 **FIGURE 9.**—Contrast multiplier required to achieve average contrast sensitivity of group (40-50 year age group).

FIGURE 10.—Contrast multiplier required to achieve average contrast sensitivity of group 50-60 year age group).

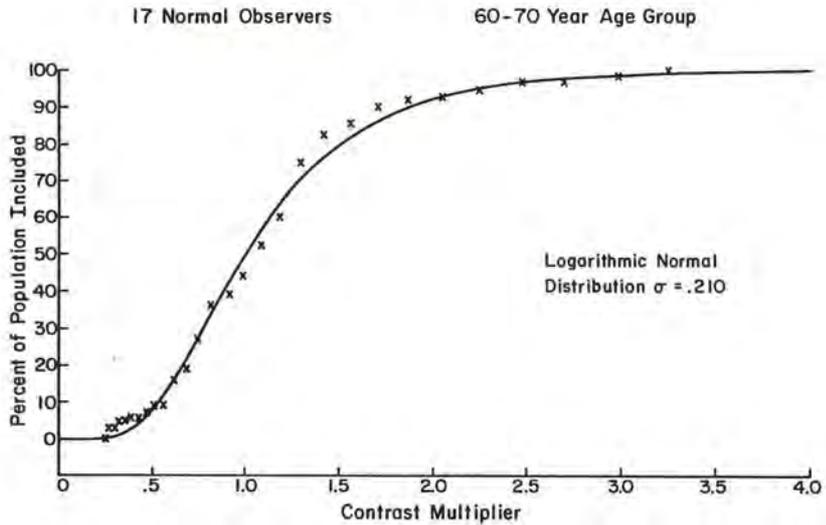


FIGURE 11.—Contrast multiplier required to achieve average contrast sensitivity of group (60-70 year age group).

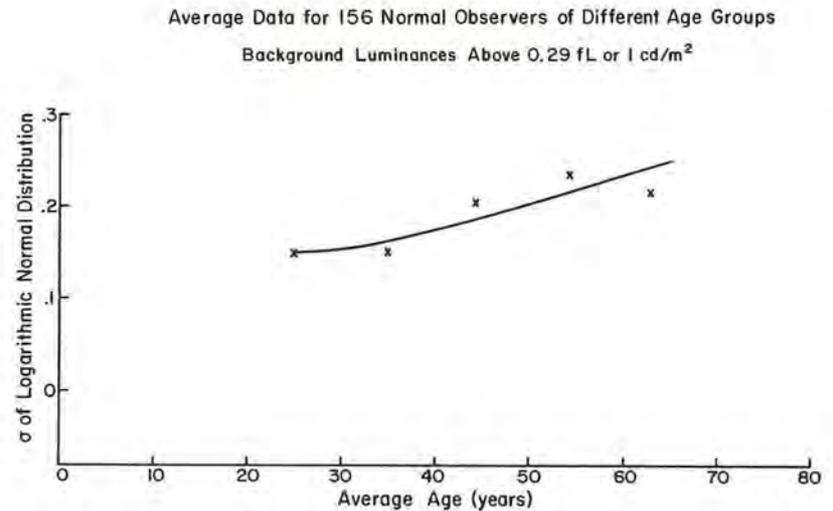


FIGURE 12.—Observer variability for the age groups tested.

distances from the threshold curves for the extreme individuals (dotted curves) to the VL 8 curve are not the same as the distance from the reference curve to the VL 8 curve. Thus, it is clear that these individuals will be provided a visibility level either lower or higher than that provided the average observer by the lighting recommendations. Figure 14 illustrates the effect on the visibility level (VL) of the average difference in contrast thresholds between two different populations, one the reference population of average age 25 and the other population of average age 50. The solid bell-shaped curve is the one shown in the previous figure and represents the range of individual differences among members of the reference population. The dashed bell-shaped curve represents the range of individual differences in the older age group. Note that, although the distributions of thresholds for individuals in these two populations overlap, the average threshold contrast is higher for the older age group. Thus VL 8 for the reference population would actually correspond to VL 5.1 for the average observer of the older group. Figure 15 shows the full data for all 156 observers in our study. Again the bottom solid line is the visibility reference function or the average contrast threshold curve for the 20-30 year-olds. The two dashed curves show the least sensitive and most sensitive individuals. Each bell-shaped distribution represents observers in a decade of life with the 20-30 year group the lowest, the 60-70 the highest, and the others in between. Note the large overlap in the distributions. Again we can see the great significance of these individual differences with reference to a particular criterion visibility level, in this case VL 8, the upper solid curve. Reduced sensitivity shows up on the graph as the need for increased contrast or equivalent contrast. Thus, visibility level will be reduced for observers having less sensitivity than the average observers in the 20-30 year age group whose thresholds were used to define visibility level. Observers with greater sensitivity than the reference population will have a greater suprathreshold visibility than the given value. It is clear from this figure that this effect is a very large one. Indeed, the least sensitive ob-

server will have less than threshold visibility at VL8.

Figure 16 illustrates a more useful form of the population data. Here we have plotted the percentage of the 20-30 year old reference population having a contrast sensitivity multiplier equal to the value on the abscissa or more. 50% of this population has a contrast multiplier of 1 by definition since this is the visibility reference population. This curve can be used to evaluate the visual performance to be achieved by different proportions of this population for any value of effective visibility level which might be selected as a visibility criterion, simply by multiplying the contrast sensitivity multiplier by the criterion VL or visibility level. This will give suprathreshold factors for different proportions of this population for the criterion visibility level. How this can be applied is illustrated in the next two figures. Figure 17 shows the same kind of a curve for a population extending from age 20 to age 70 with proportional representation in accordance with the 1970 U.S. census. Now suppose we want to know the effect of the present criterion Visibility Level for lighting standards in this country on this population. We simply multiply the Contrast Sensitivity Multiplier by VL8 and can then plot a graph such as Figure 18 which shows the percentage of individuals in this normal population attaining a given suprathreshold factor or better when the criterion VL is 8. Referring to the solid line on the graph, it can be seen that 27.8% of this 20-70 year old normal population have individual suprathreshold factors equal to or greater than VL8. The average of the population has a suprathreshold factor of 5.7 instead of the recommended 8.

The dotted line on the graph shows the result of changing the criterion visibility level from 8 to 7.29 which represents a cut in illumination levels from 100 down to 50 fc. In this case only 22% of the population has VL 8 or better. The average VL is actually only 5.4. Thus, 6% more of the population will not have the criterion visibility level.

Thus we have developed a technique by which you can see our present best estimate of the effect of a change in the criterion effective visibility level on any population of interest.

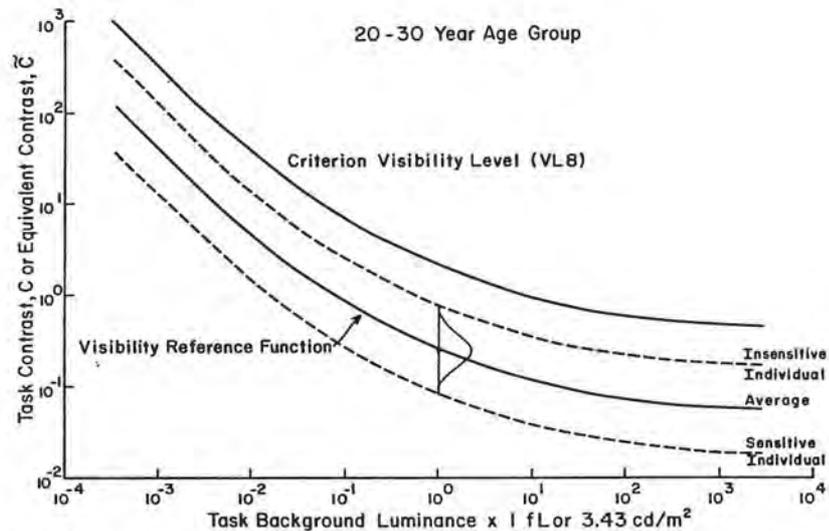


FIGURE 13.—The effect of individual differences in threshold visibility among 20-30 year olds on the significance of a criterion visibility level.

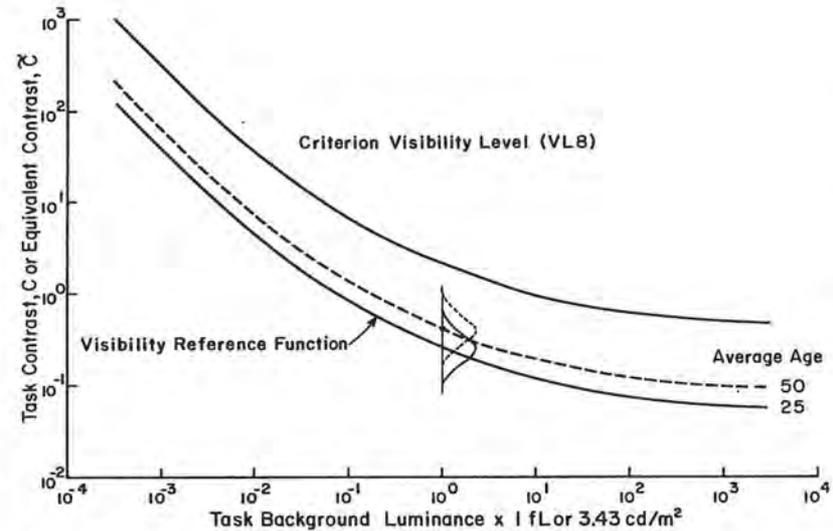


FIGURE 14.—The effect of an average difference in threshold visibility between two different age groups on the significance of a criterion visibility level.

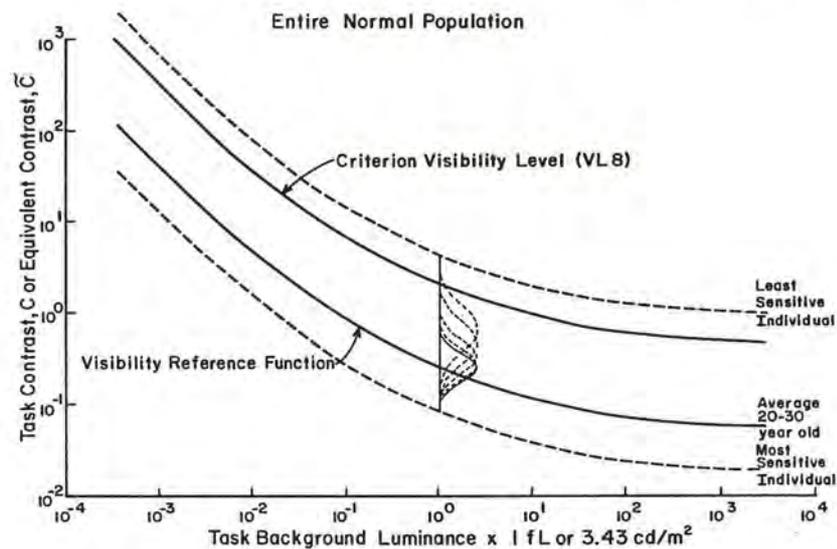


FIGURE 15.—The effect of individual differences in threshold visibility in the entire normal population on the significance of a criterion visibility level.

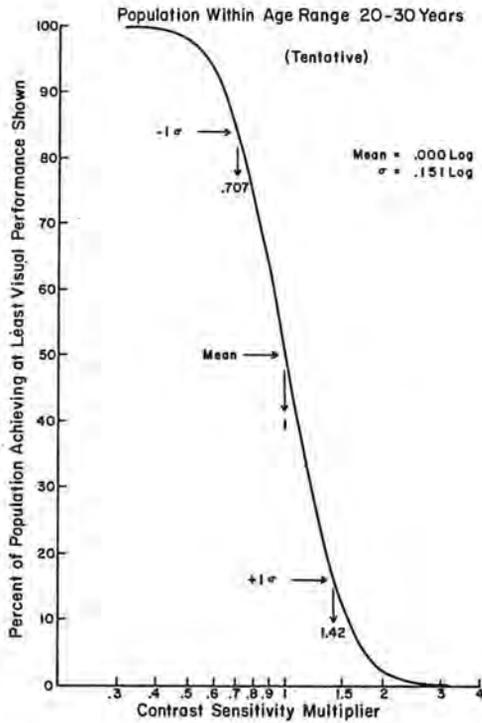


FIGURE 16.—Percentage of reference population having a given contrast sensitivity multiplier or greater.

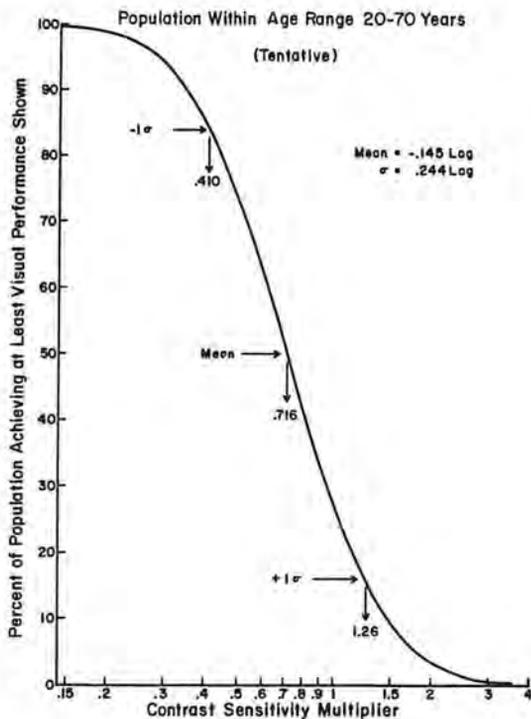


FIGURE 17.—Percentage of total population having a given contrast sensitivity multiplier or greater.

Dr. Blackwell: Now, thinking that the thing you really wanted to know about was not performance but health, we managed to get records of what it is you do when you give an observer different levels of suprathreshold factor. We have used our Purkinje Image Eye Tracker, developed by Stanford Research Institute, and had one observer first obtain her own threshold for a particular test object, and then we measured her ocular motor function as a function of how far above that threshold we were. We started with a visibility level of eight, which is the one currently used in the IES system, and systematically reduced the visibility level until we got down to two, the point at which we say she should barely see the target all the time; and we measured two classes of ocular motor responses. Incidentally, we got some symptomatic complaints par excellence as our observer told us what we had not dared to ask about how she felt about our low levels of visibility.

The first of these we used—I am sorry, Dr. Fry, maybe it is not a good measure, but it sure is a sensitive one—was steady fixation. This was Dr. Hebbard's task exactly; and what we did was have an observer look at a single four-minute spot of light which we had previously measured threshold on using the CIE system. In that case, we put on fixation lights. Then we took the fixation lights away and had one dot in a large screen, started with a visibility level of eight, and told her to steadily fixate it. These are the results of the X and Y coordinates of her ability to fixate. This is an extremely fine machine and we had just gotten it and it measures—these excursions are about six minutes of arc total extent and this observer is a very good observer and able to maintain excellent fixation—but what it means is that—remember the Hebbard experiment? The graph is a time scan. This is the X and Y coordinate of a system in which, if there were perfect stability fixation, the things would be two straight lines. The observer is told to look at a dot and hold her two eyes directly on the dot. These are not two eyes. These are one eye. The machine measures by means of two servos, infrared, one locked onto the first Purkinje image, one picking up the fourth Purkinje image, and translating the motion needed for *servo optimization* of the signal and of XY coordinates, put onto an oscilloscope. By measuring the amplitude we are able to determine the extent

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Entire Normal Population Ages 20-70 Years

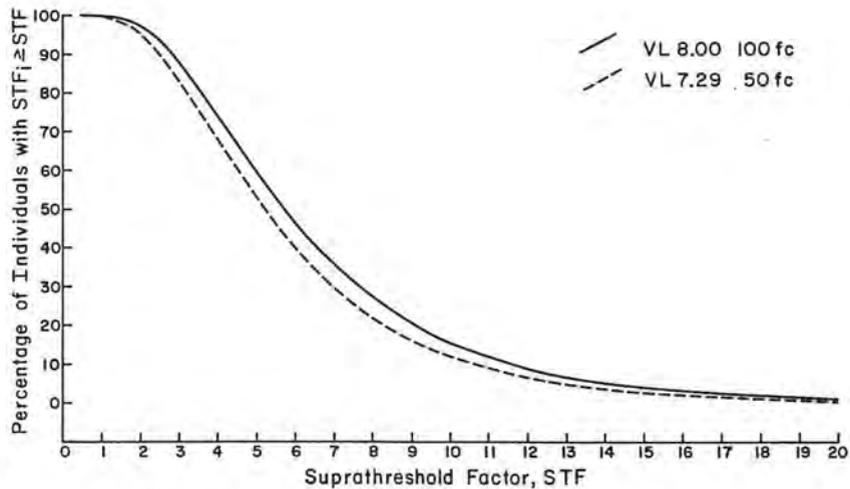


FIGURE 18.—Percentage of total population attaining a given suprathereshold factor or better at VL8 and 7.29.

to which she can maintain steady fixation.

Hebbard's experiment has been discussed so much. It is shown here, together with my interpretation of it. I took Hebbard's actual visual display, which was the little ring of light. He told his observers, as I told mine, to look at this steadily. Using the contact lens method that you saw a photograph of, he recorded the extent to which you could not do this, the extent to which the eye oscillated in trying to hold steady fixation. He varied both the contrast of the target and the light level by a factor of one hundred to one. Later, I took a visibility meter and measured the visibility of this particular display and replotted his data in terms of what was then called the relative visibility factor. To get it into modern language, one on that scale is VL 8. This was put in terms of the IES method.

This showed the same phenomenon that I am able to show you here more directly with my records; namely, that if you begin to cut the visibility level below eight, there begins to develop an inability to maintain an accurate sharp focus. Reducing the information to the servo system, opening up the loop, and the thing starts to chatter. And that is what that shows. As the visibility level goes down from eight, which is one on the scale, to 4 which is

0.5 on the scale, there has been a certain increase in the variability of steady ocular fixation. Now, we have here the records so you can study them to show you what this looks like in terms of time. It turned out to be very interesting indeed because you will see that what happens is that one can do this reasonably well for a limited time when visibility level is cut but, then, the system goes berserk and completely loses ability to do it. That is to say you get fairly good behavior for a while and, then, suddenly a great big excursion that puts the record off the paper and the eye tries to come back and do it again, in short, a big movement. The time per inch is one millimeter per second. I also have some nice strip charts that are at five millimeters per second for us to study tomorrow. The frequency is very rapid. It is physiological nystagmus that we are picking up. I am sorry. I just wanted to say I had it; tomorrow we can study it. I wanted to say that we did these experiments to find out the consequences in ocular motor function of changing visibility level. This experiment had been done years ago but had the defect that we did not have the same observer measure his own threshold. This was done by the method that I measured the visibility of the task long after he had done the experiment and I used as a reference point the average twenty

to thirty-year-old observer. The direct way to do it is to take the same human being and the same machine, have them measure their own threshold, and, then, deliberately increase the contrast above that and find out exactly how it comes out. What I am trying to say is that I have here records that show that, indeed, this happens; and it happens about the same as is shown on the graph when I do it in the most sensitive and direct way.

I can show you tomorrow, with more time, two interesting aspects of the behavior. One aspect of the behavior is that at VL 5 things begin to happen; at four it is much worse; at two it is almost impossible, as you might imagine. With the steps I took—eight, six, five, four and two—by the time I got to two, the observer is almost unable to see it. There are long periods in which she has lost it and her eyes move so far as to go off the record. Then she will find it again and we are able to latch onto her with a machine and go again. So one aspect of it is that performance is not uniformly bad over time. You do pretty well for a little bit and then go and lose it altogether. So there is a *temporal* factor that Hebbard's data did not show because he did not present them in that form.

And, secondly, the most interesting thing was that this behavior deteriorates rather quickly. If you measure it for only five or ten minutes at a low visibility level, the observer does, in some ways, remarkably well. But make her do it for fifteen minutes and two things happen. One, the behavior is dramatically worse. I have records — the first time I did it and after fifteen minutes I did it again; you can see for yourself. Finally, she began to lacrimate and to complain. Now, at what point, exactly, did she begin to complain? Surely at VL 4 she complained. VL 2 was impossible. VL 5 and 6, some complaints. But my instinct was that VL 4 or somewhere around there is where trouble would start to occur. Well, this, of course, is not proof; but it does show that it is not a difficult matter to find out that, if you begin to reduce visibility much below eight, there is a change in the ocular motor performance.

Now, I did one more experiment that had never been done before, which I thought might be a better test, since I knew there were some objections to the steady fixation test. We had her look from one point in space to another.

In the first experiment I have here, we had her looking from one Landolt ring to another when they were 1.75 degrees apart. You can look at the smoothness with which she made the shifts. We said, "Left, right, left, right," and did it at various visibility levels. The data show the same phenomena as before. As you go down in visibility level, suprathreshold factor for her, you can see that she begins to do this much less well and, again, after fifteen minutes, much, much worse than before; and, again, she begins to make some dramatic complaints.

We did this Monday. Tuesday, the last day we had, we did one other experiment, because once she anticipated me — I did not say move and she moved. I began to wonder whether she was not doing spuriously well by paying no attention at all to what was supposed to be seen but just making the same movements in magnitude from memory. Subjects are rather good at this; you have to watch it. So I set up, the next day, five dots, better than Landolt rings because there is an ambiguity in Landolt rings about where you should direct your eye, at the middle or the edges or what. I measured the threshold for these, repeated the experiment—I have long strips I can show you tomorrow — and got essentially the same results, only in this case I completely kept her from guessing what I was going to ask for by changing my commands. I had her look at the center of the array and go either up, down, left or right and kept mixing them up. But the conclusion is the same. You can definitely find out that, when you begin to cut the V.L. down, certainly to four, five and six, there definitely is a loss in the ability of the ocular motor systems to function and there are symptomatic complaints. She lacrimated, under all these experiments, when the visibility level was about four.

Now, the interesting thing is, if you can believe what we have presented to you here, it says that there are a lot of people in the population who should have similar problems. There are, in fact, some that will have similar problems at IES recommended illumination levels. There certainly are a few more, at least, who would have complaints at reduced luminance levels. And, in a sense, then, this was, if you will, a kind of an effort to see if we could believe those people who came to the GSA and started all this off by saying that they felt the

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light levels were causing them symptomatic complaints. We have not proved this; but, in a sense, I think I satisfied myself—two more years of research would probably prove it—that very likely some people in the population at current light levels, and some more at reduced light levels, have the basis for symptomatic complaints, because we are not giving them enough visibility above their threshold to drive their ocular motor systems in an adequate way. What we need, of course, is to have a very accurate definition of the point at which we get into trouble and I can not claim I have that. We would have to have lots of observers; we would have to see whether this is the rectifying variable, that, if we took observers with different sensitivities, they all had ocular motor troubles at the same suprathreshold factor. We expect the ones with low sensitivity, who are older, to have trouble sooner, if anything, because our dynamic performance data on older people show that they lose more than just sensitivity as they get older. They lose ocular motor motility as well.

And so, in a sense, we think that this has proved to us to be a useful way to look at the problem. What do you do, from a performance point of view and a symptomatic point of view, if you cut light levels? We think the individual differences in observers are astonishingly large. This has been confirmed by three different experiments by three different people. Vos and Bauman and Lazet did one, Smith did another, and my wife and I did the third. And they all showed the same thing; these differences really are there. They are not methodological; they are not people not paying attention to the experiment; the sensitivities really do vary as much as this and do have a direct effect on performance. We measured forty-eight people, measured their sensitivities and measured their performance and have shown that these sensitivity changes show up directly in performance. People differ in performance, also, by taking account of their threshold differences, which reduces the variance of the data enormously. So we think this is really what you are doing when you cut your light levels in half.

Now, I should say, and we can expand on this tomorrow, that one big catch is that we have talked entirely in terms of a visibility level criterion. You know the way the thing works, you pick a visibility level criterion—eight, seven, whatever it might be—let us say

that Great Britain picked 7.29 and the U.S. picked 8. Now, having done that, you do not get a light level until you have done one thing more and that is to decide what visual task is important. Now, let us suppose that there are villains in the audience with commercial interests. If they pick the right V.L., it is still going to influence the light levels a great deal by picking unreasonable tasks. And so, I just remind you that whenever the V.L. part is what we are concerned about, the selection of tasks, also, has a large effect on illumination levels. Bold print requires one; dim print requires a hundred footcandles. Now, someone else has to decide, not us, what reasonable tasks are. But, again, to us, the visibility level is what lighting is all about. We recognize there are other aspects of it covered by suprathreshold clarity, such as the pleasantness of lighting which are not included. But we believe we have some feel now for what you are doing by cutting light level.

Incidentally, you might be amused, as one last remark, the university, of all things, asked me if I would please advise their "Energy Saving Department" on how and where to remove light bulbs. I suspect that they wanted me to bless their taking out half the light bulbs in the university. I soon discovered that is what they really wanted me to do. They said, "You must tell us tomorrow; we have to start tomorrow. You have no time. What do we do? We start tomorrow. We want to save half the energy in the university." So, looking at my wife's curve showing the abrupt change at forty-five age, I made one simple rule which they have followed. They reduced the light level differentially for those below forty-five years and those above. Fortunately, in a university, the populations are rather separate; most of the professors are over forty-five and the students are a great deal under. And so, all the cut is being taken out of the young age group in classrooms and the professors' offices are being left alone. I still think that is not a bad day's work, and it was the best thing we could do under the circumstances. Dr. Weale's data provided partial explanation. Older people need more light, as he said, a factor of three. Well, then, in a sense, I have given them twice as much by not taking away what they had. I did not realize the number was three; but, in a sense, I did not do a bad job of thumbnail engineering.

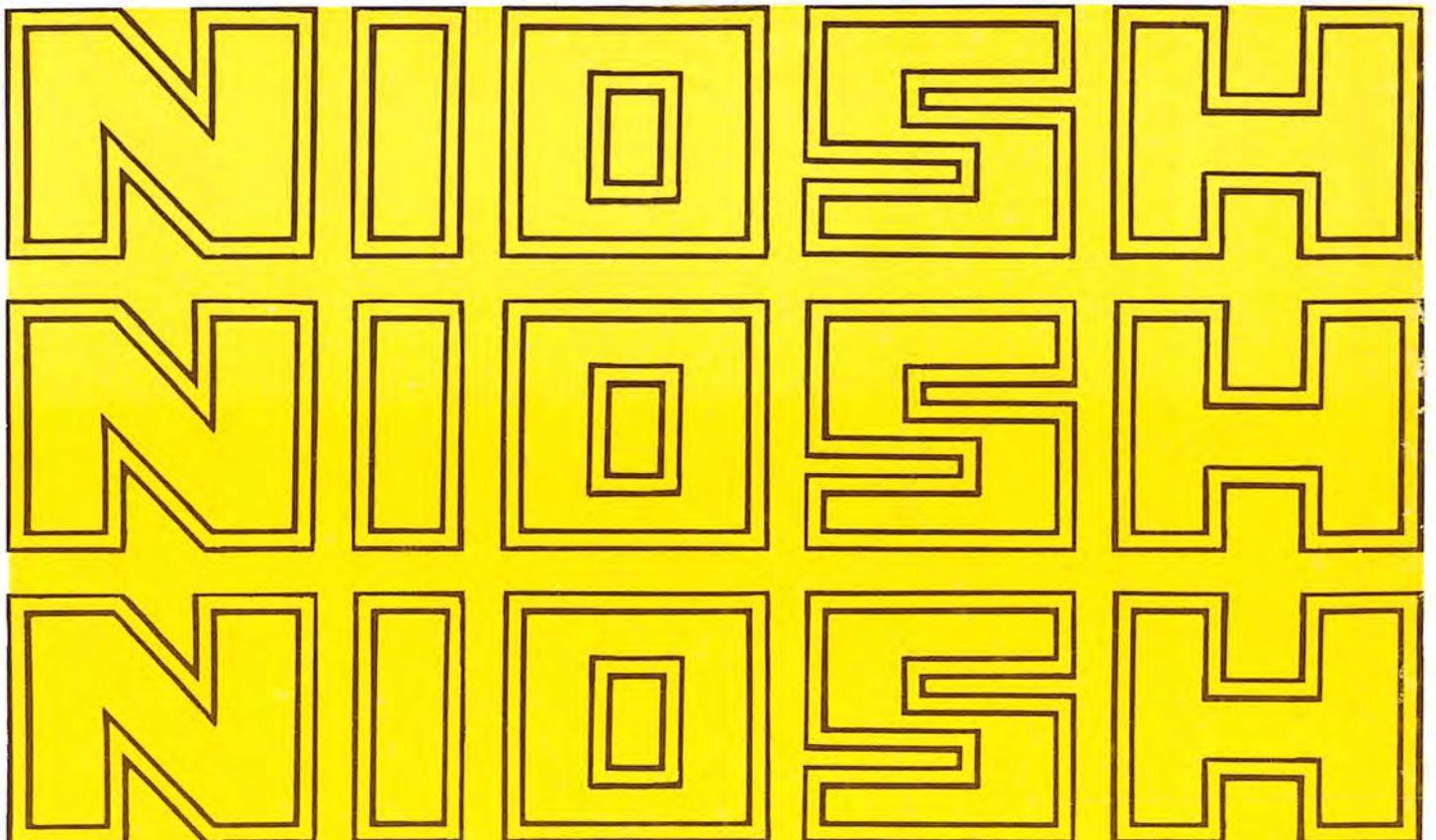
NIOSH

**The Occupational
Safety and Health Effects
Associated with
Reduced Levels of
Illumination**

Proceedings of Symposium

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**THE OCCUPATIONAL SAFETY AND HEALTH EFFECTS
ASSOCIATED WITH REDUCED LEVELS OF ILLUMINATION**

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Symposium Chairman

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