TRANSACTION IES

Visual Performance:

A Comparison in Terms of Detection of Presence and Discrimination of Detail

By Sylvester K. Guth and John F. McNelis

A GREAT deal of information has been obtained by many investigators on the threshold relationships between contrast and luminance. These all follow the same general pattern: smaller contrasts can be seen with higher luminances. However, differences in experimental procedures, criteria, test targets and observers make direct comparison difficult. For example, the results obtained by three groups of investigators[1, 2, 3] are shown in Fig. 1. As can be seen, the form of the curves and the absolute values of contrast are different, even though the nominal sizes of the targets were very nearly the same (four minutes). For a range of luminances from one to 100 footlamberts, the data for the Landolt ring (curve B) result in a flatter curve than do those for the parallel bar (curve A) and disc (curve C) targets. Such differences have led some to express concern that the basic relationships for one type of test object may not be applicable to others. They feel this may indicate inappropriate lighting recommendations for many practical tasks which bear little resemblance to the object used for the standard visual performance curve used by the IES.[4]

In his 1959 paper,[5] Blackwell did point out that errors would be introduced into the lighting specification method due to non-parallelism of threshold curves obtained with various visual tasks. He presented data illustrating the differences obtained for the detection threshold with crosses, rectangles and circular disc targets. However, he suggested that differences in the form of the curves can be minimized by evaluating a task at a luminance level as close as possible to the one specified by his system. Furthermore, the curve for the four-minute disc, which was selected as the standard, was roughly of intermediate form with respect to the others. Since all of his data are in terms of the detection of the presence of the target, we still have the question of possible differences when discrimination of detail is involved.

For present purposes our primary concern is with the shape of the contrast-luminance relationship when the criteria of detection of presence and discrimination of detail are employed. That is, are the differences in the shapes of the curves shown in Fig. 1 caused by the criteria and types of test objects, or by other factors? Thus, the objective of the present investigation was to compare threshold data for a disc target with similar data for two objects—a parallel bar and a Landolt ring—which involve discrimination of detail. It is obvious that many other types of targets could be used, but these should indicate what might be expected and will provide a check with the curves of Fig. 1. Furthermore, these two objects also lend themselves to observations using the criterion of detection of presence, and thus permit an additional comparison.

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Apparatus and Procedure

The apparatus used was a new instrument which has been described in detail elsewhere.[6] In essence, it is an optical device which permits presenting targets that are either darker or brighter than the background, while keeping the background luminance constant. In the present investigation the targets always were brighter than the background. A variable density wedge in the optical system was used to vary the target contrast from sub to suprathreshold conditions. An image of the target was projected through an aperture in the center of a large trans-illuminated screen so as to appear in the plane of its front surface. The viewing distance was one meter. The uniformly illuminated screen extended 64 degrees vertically and 86 degrees horizontally, and thus filled a significant part of the field of view. The luminance of the immediate background (obtained through the instrument) and that of the surrounding field were adjusted to be identical. In other words, the target was viewed against an extensive uniform luminous field.

Background luminances of one, 10, 100 and 500 footlamberts were used, and the exposure time was 0.2 second. These encompass the range used by Blackwell and Smith for developing the standard perforance curve[4] and permit direct comparison of the results.

The three test targets used are shown in Fig. 2. The critical detail in all cases was four minutes of arc. The disc, of course, is the same as that used as the basis for the standard performance curve.

The method of limits and a "yes-no" subjective

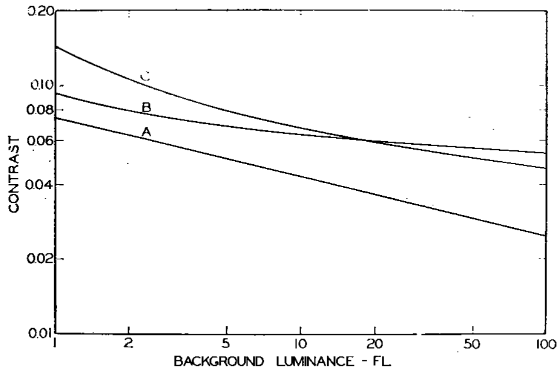

Figure 1. Threshold relationships for three types of test objects. A: 3.95-minute parallel bar (Cobb and Moss); B: 4-5-minute Landolt ring (Conner and Ganoung, after Fry); C: 4-minute disc (Blackwell and Smith).

response were used. The target luminance was varied in fixed steps corresponding to changes in contrast ranging from six to 10 per cent, depending upon the background luminance. Each experimental session consisted of about 320 target presentations, 80 for each of the four background luminances. Since relative, rather than absolute contrast values were desired, two experienced observers participated. Each session was repeated four times, thus each data point represents the mean of 80 final threshold determinations. The observers had full knowledge of the configuration of the target, the moment of its presentation and where it would appear.

Results

Disc. The first step was to obtain threshold data for the four-minute disc target to determine how well our results compared with those obtained by Blackwell and Smith. The mean values are given on line A of Table 1 and are plotted in Fig. 3. Also shown on line G, Table I, and as the dashed curve in Fig. 3 are the Blackwell-Smith data. The latter threshold curve has been derived from the standard performance curve[4] by dividing the contrast values by 13.34

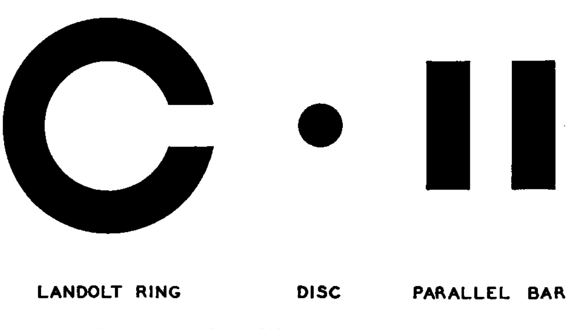

Figure 2. The test targets used in the present investigation. The critical detail is the same in all cases.

—*i.e.*, allowing for the field factor and the conversion to 99 per cent accuracy. It can be seen that the two curves are almost exactly parallel. Ratios between our values and those of Blackwell and Smith for the four luminance levels are 1.77, 1.61, 1.72 and 1.67, with an average of 1.69.

It is interesting to note that Blackwell[5] has pointed out that the "yes-no" method yields threshold contrasts about 1.2 times as large as the forced-choice method when experienced observers are used. When comparing naive (yes-no) with experienced (forced-choice) observers, the factor was 2.4. The ratio of 1.69 is approximately midway between Blackwell's factors and is an indication that our values appear to be about what one would expect on an absolute basis. Of course, the parallelism is of greatest importance because it shows the effect of background luminance on threshold contrast to be the same for both groups of data. It confirms the shape of the standard curve as published in the *IES Lighting Handbook,* Fourth Edition, in the region of greatest interest for interior lighting practice.

Parallel bar. Average threshold data for the parallel-bar test object are given on lines B (detail) and C (presence) of Table I and are plotted in Fig. 4. Also shown in the latter (dashed curve) are the Blackwell-Smith threshold data for a disc. It is evi-

Table I—Threshold Contrasts for Detection of Presence and Discrimination of Detail for Three Types of Test Targets. The Exposure Time Was 0.2 second.

Target and Criterion	Background luminance-fL 1	10	100	500
A. Disc—presence	0.252	0.108	0.079	0.065
B. Parallel bar—detail	.135	.062	.036	.026
C. Parallel bar—presence	.087	.046	.030	.023
D. Landolt ring—detail	.154	.089	.070	.059
E. Landolt ring—presence	.089	.053	.042	.037
F. Mean of all data	.132	.068	.048	.038
G. Disc—Blackwell-Smith	.142	.067	.046	.039

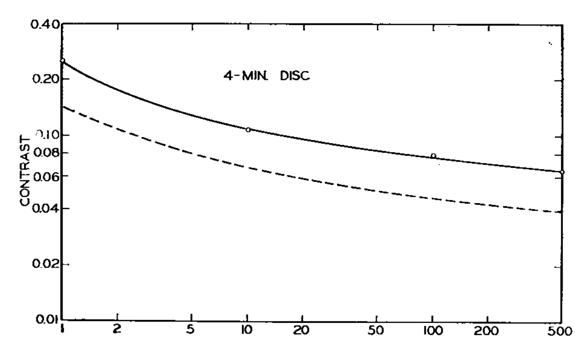

Figure 3. Threshold contrast relationships for the detection of presence of a 4-minute disc target and an exposure time of 0.2 second. Solid curve—present investigation; dashed curve—Blackwell-Smith data.

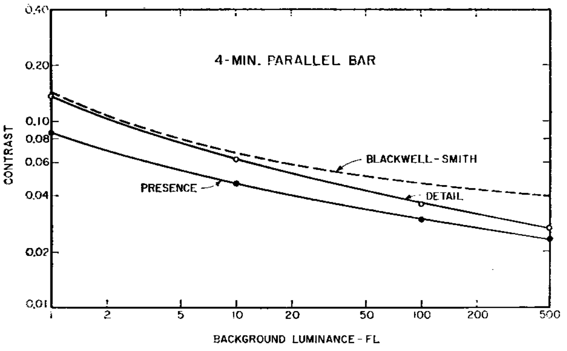

Figure 4. Threshold contrast relationships for the discrimination of detail and detection of the presence of a 4-minute parallel-bar test object as compared with that for the detection of a disc (dashed curve). The exposure time was 0.2 second.

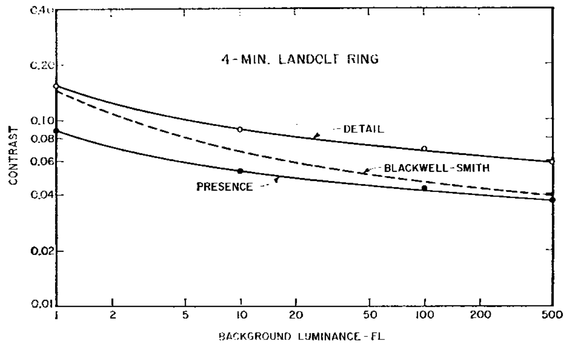

Figure 5. Threshold contrast relationships for the discrimination of detail and detection of presence of a 4-minute Landolt-ring test object as compared with that for the detection of a disc (dashed curve). The exposure time was 0.2 second.

dent that the curves for the parallel bar are somewhat steeper than those for the disc. Furthermore, the curves for presence and detail are not parallel.

It appears that there are somewhat different functional relationships for the parallel bar and the disc. As a matter of fact, the relationship for the parallel bar seems to approach those of elongated rectangles and crosses as reported by Blackwell.[5] The steeper curves indicate that a given contrast would require a lower luminance level for a specific degree of suprathreshold visibility than is specified by the Blackwell-Smith curve. Or, putting it another way, a loss in contrast at a given luminance level will require a smaller increase in compensatory luminance.

Landolt ring. Data for the Landolt ring are given on lines D and E of Table I and are plotted in Fig. 5. The curves for discrimination of detail and detection of presence are very nearly parallel to each other but are flatter than the Blackwell-Smith relationship (dashed curve). In other words, the relationship for a disc target does not represent visual tasks which correspond to Landolt rings.

Comparisons

A comparison of these new data with those obtained by earlier investigators is of interest. It has been shown (Fig. 3) that there is excellent agreement on a relative basis for a disc target between our values of contrast and those of Blackwell and Smith. Differences in absolute values, being about 70 per cent higher in contrast, can be attributed in part to different experimental procedures—yes-no *vs* forced-choice—and to differences in observers, including age.

Threshold contrasts for the parallel-bar and Landolt-ring targets are in essential agreement with the corresponding curves A and B in Fig. 1. That is, the functional relationships seem to be governed by the type of target and not by experimental procedures or observers. The last two factors, of course, will influence absolute values of contrast. In all three cases, our values of threshold contrast are higher than those indicated in Fig. 1, but the relative ranking of contrasts is the same. As seen in Table I, contrasts progressively increase for parallel bars, Landolt rings and disc targets.

Differences in functional relationships for several types of targets have been demonstrated by Blackwell.[5] His data also indicate that differences are influenced by exposure time and size of target. However, for purposes of determining illumination requirements for equal visibility it has been found to be practical to adopt some sort of a standard basis. Certainly, it would be desirable to have a family of specification curves so that each actual visual task can be related to the most appropriate one. But this would introduce considerable complexity and probably much controversy as to which curve should be used for a specific visual task. In other words, a single specification curve is a very practical approach.

The parallel-bar and Landolt-ring targets probably represent moderately extreme types of visual tasks. In

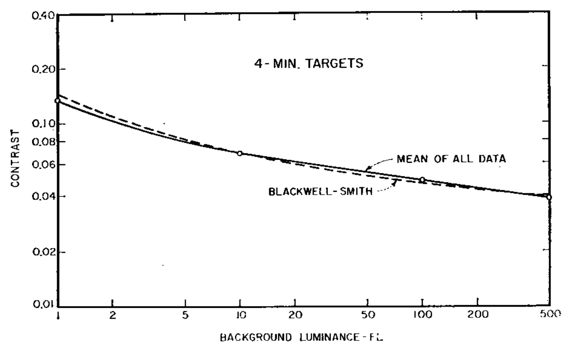

Figure 6. Mean threshold contrast relationships for all targets and criteria included in the present investigation as compared with the Blackwell-Smith threshold curve.

the former, the detail to be discriminated consists of the long narrow space between bars. The length plays a significant part in its higher visibility—*i.e.*, lower threshold contrast—than those of the disc and Landolt ring. On the other hand, the critical detail of the Landolt ring is a small square gap having very nearly the same area as the disc. The presence of the ring provides an additional clue or stimulus which results in a somewhat better visibility than for the disc. For the criterion of detection of presence, the total areas of the parallel bar and Landolt ring are considerably larger and therefore result in lower contrasts than that obtained with the disc. In fact, in terms of area, the parallel bar and Landolt ring correspond approximately to 11-minute and 15-minute discs, respectively.

Functionally, as is evident from Figs. 4 and 5, there is relatively small difference between detection of presence and discrimination of detail for the parallel bar and for the Landolt ring. The form of the curve for the disc is about midway between those of the other two targets. This leads one to speculate on how well the functional relationship of the disc represents an average value. The means of all data obtained in this investigation are given on line F of Table I and are plotted in Fig. 6, along with the threshold values derived from the standard performance curve (Blackwell-Smith). As can be seen, the average curve agrees very well with the standard threshold curve not only in form but on an absolute basis.

From the mean of all data presented in this paper, it may be concluded that the performance curve published in the *IES Lighting Handbook*, Fourth Edition, does provide an *average* basis for determining lighting levels needed for adequate visibility. Of course, if it can be demonstrated that most practical visual tasks follow the relationship exhibited, for example, by the parallel-bar target, it will be necessary to adopt a different performance curve which more truly represents the actual function between contrast and luminance. The determination of this will require extensive threshold data for a wide variety of types and sizes of test objects and exposure times corresponding to those involved with typical visual tasks.

References

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DISCUSSION

G. A. FRY:* An interesting thing about the Landolt-ring target is that it can be regarded as equivalent to two rectangular bars placed end to end instead of side by side as in the parallel-bar target. If such a target is substituted for the Landolt ring, one can make a transition from the one pair of rectangles to the other.

In a previous paper[1] I have pointed out the relation of the parallel-bar target to the disc-annulus target used to test the effect of the outside border of the annulus on the visibility of the disc. Looked at in this light, it is not the bars that constitute the target, but the gap between the bars. In terms of the disc-annulus target, one can say that detection occurs when the outside border of the annulus is visible and that resolution occurs when the inside border is visible. It may be shown that the presence of the outside border interferes with the visibility of the inside border.

In terms of the IES system of prescribing illuminance levels, one can ignore this physiological problem, because in practice what we do is to measure the average luminance of the two-degree area centered on the critical detail and then measure the threshold of visibility by a patch of veiling luminance. Operationally, therefore, Guth and McNelis have done the proper thing when they specify the luminance of the field upon which the Landolt-ring and parallel-bar targets are superimposed as background luminance and the contrast between bars and their background. These are the variables manipulated in using veiling luminance to measure the threshold and this makes it possible to compare the bars with a disc.

If the luminance of the gap between the bars had been varied to measure the threshold, it would have been impossible to relate the data to the veiling luminance method.

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1. G. A. Fry. "Monocular Measurement of Visual Acuity Corrected," *Optometric Weekly*, Vol. 37, 1946, p. 1795.

H. RICHARD BLACKWELL:* This paper is an excellent addition to our growing information on the effects of illumination quantity upon visual performance. The authors have dissected the problem of different tasks in an expert fashion and have shown that, indeed, the contrast-luminance contour for equal performance is not identical for different tasks just as I suggested some years ago. They also showed that, as I have always thought, the contour for a 4-minute disc target is a good average of the contours obtained with tasks as different from disc detection as detection and resolution of parallel bars and Landolt rings.

One additional aspect of their data is of special interest because of its relation to the data my wife and I are reporting to the Society in a paper scheduled to be published in April IE. The authors show that the contrast-luminance contours for detection and resolution of detail for Landolt rings are parallel. This is precisely the result we have shown in our measurement of iso-suprathreshold contrast acuity. Of course it is interesting to find that this parallelism does not occur

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for parallel-bar targets. This result agrees with recent work I have reported in which disc detection and grating resolution have been shown to involve different mechanisms of retinal neural organization.

HENRY L. LOGAN:* This work of Guth and McNelis presents a welcome confirmation of the validity of the Blackwell-Smith standard performance curve as a good, practical average basis for determining lighting levels needed for satisfactory visibility.

It does raise a question about applying the disc-target results to specific situations where the target shape is radically different, but as this whole matter becomes essentially statistical in nature, it seems to me that the authors have presented evidence only showing that targets exist which depart asymmetrically from the mean periodicity curve of the disc target. Putting it another way, they have developed some confirmation of the conclusion that the disc target does represent the type of target which gives the mean periodicity curve, and that results obtained with other targets will all depart one side or the other from this mean curve, as is to be expected in any statistical situation. In a practical sense this departure is only of technical interest, and I do not go along with the authors' suggestion that further investigation of other targets may make it "necessary to adopt a different performance curve."

Further investigation is always desirable. We can never know enough; but if in a large scale industrial situation it is discovered that the statistically most frequent target follows a different curve than the disc target, one which would call for lower lighting levels, I do not think it would be a good thing for the industrialist to go to lower lighting levels, because there are other benefits of higher lighting levels which outweigh the minimum visibility benefits.

In an economy of scarcity, where electric power is expensive, and maybe even rationed, it might be economically desirable to go to the lowest possible lighting level at which satisfactory visibility can be secured, but that is hardly the case in the United States.

In fact, other considerations such as the bio-effects of light levels are now coming to the fore, which indicate much higher levels than are required for technical visibility; so that data of this sort, desirable as it is in the light of increasing knowledge, will tend to become "academic" in high level technological societies.

DOMINA EBERLE SPENCER:** It is most refreshing to find the name of Dr. Guth appearing as author of a paper on visual performance. And it is delightful to read such an excellent paper. The experimental results give smooth and reasonable curves. And the differences between the various sets of data are analyzed carefully and well.

There is only one change that would seem to me to be desirable. If the *delos* had been plotted, instead of contrast, then the Guth-McNelis data and the Blackwell-Smith data of Fig. 3 would be in perfect agreement. And the discrepancies between the various sets of data in Figs. 4 and 5 would be minimized. And it appears to me that the *delos* is closer to the specification of a concept of true human significance.

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SYLVESTER K. GUTH and JOHN F. MCNELIS:* As Dr. Fry pointed out, the space between the two parallel bars is the target when the criterion is discrimination of detail. However, the forms of the test object—two straight bars separated by a gap as compared to a single bar curved into a broken annulus—provide different clues to the observer. This is illustrated by the non-parallelism of the threshold curves for the parallel bar and Landolt ring. It would be interesting to determine the effect when the length and width of end-to-end bars are varied for a constant space between them. By this means one could develop the transition from the Landolt ring to the parallel bars. There obviously are many types of targets one could devise for such investigations and they would provide much useful data. However, the primary purpose of the present work was to determine the degree of parallelism of the contrast-luminance relationships for several simple target configurations.

We were quite sure that Dr. Blackwell would be as pleased as we about the confirming nature of our results. We hope that they will eliminate much of the concern which has been expressed regarding the apparent uniqueness of the disc type target used by Dr. Blackwell and his associates. This, of course, does not mean that we do not need further data for other types of task configurations in order to keep improving our basis for lighting level requirements.

We doubt that Dr. Logan need be concerned about lower lighting levels being indicated by the contrast-luminance relationships for certain types of test objects. It is true that a steeper curve would do this. But it must be remembered that these are threshold values. When the curves are adjusted upward for suprathreshold visibility, even that for the parallel-bar test object will indicate the need for lighting levels considerably above those being recommended for typical practical visual tasks.

Our present results indicate that the disc does represent a good average for the three types of targets used in the investigation. But we still have inadequate information about how representative it is of the wide variety of visual tasks encountered in the work-world. It is true that one can think of individual curves as illustrating the deviations from an average curve. However, the few we have shown would indicate some sort of a skewed distribution, the degree and direction of which appears to be a function of luminance level as well as target configuration. Thus, it seems to us that it is desirable to study other types of visual tasks to determine the best overall contrast-luminance relationship.

Dr. Logan rightly points out that visibility is only one aspect of seeing which needs to be considered when developing lighting recommendations. Ease of seeing—i.e., work and effort—and other biological effects certainly also are important.

It isn't clear to us how the *delos* concept, as suggested by Dr. Spencer, can be applied to our results with any real meaning. *Delos* is derived from ratios of visual acuities, or from ratios of background and surround luminances. If it is extended to ratios of contrast, using that for one of the conditions as a basis, the results merely become relative values. This will not change the shapes of the curves. Thus, the curves for the Blackwell-Smith and our data (Fig. 3) will be in perfect agreement. But there is good reason, as explained in the paper, why differences in absolute values are to be expected. On the other hand, the *functional* differences among the curves in Figs. 4 and 5 will remain unchanged.

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