Visual Comfort Evaluations of Roadway Lighting

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● THE VISUAL comfort quality of roadway lighting may have implications of greater importance to the over-all public welfare than the benefits of applying comfort principles in prescribing interior lighting. Visual ratings now considered adequate may be considered poor in the future. Added value and increased night use of the multi-billion dollar public investment in streets, highways, autos, trucks, and buses involves seeing comfort as well as visibility. Improved comfort for the motorist is one of the principal objectives in the advanced design of vehicles and roadways.

A recently published report (1) states: "Comfort, convenience, and safety are considerations of importance equal to a consideration of capacity in today's highway planning. This concept of adequate facilities requires modern techniques for handling traffic..."

URGENT NEED FOR RELATIVE VISUAL COMFORT RATINGS

Roadway lighting which makes night driving more pleasant and attractive is being numerically rated (5, 6, 7, 8, 9, 11, 12) in terms of relative visual comfort and relative visibility. These two seeing factors influence motorist opinion, enthusiasm, and demand for the installation and modernization of the lighting.

The Highway Safety Study Report (1) includes comment on the need for evaluation, driver research, and engineering investigation, and analysis of vision problems and driver fatigue. For example (1, 2): "...The Bureau of Public Roads has initiated appropriate cooperative studies with state authorities so that sorely needed new concepts, criteria, and techniques will be developed for determining the true value of continuous lighting on rural highways."

VISUAL BENEFIT RATINGS SHOULD ACCOMPANY RATINGS OF TRAFFIC BENEFIT

In support of such activities (2), plans for research and engineering analysis of the effectiveness of roadway lighting (3, 4), it is essestial that relative ratings be available for both visual comfort and visibility.

If roadway lighting has poor visual ratings, it is obvious that the traffic benefit produced can be expected to be less than that produced by lighting having good visual ratings.

Also of significance are the ratings in terms of relative visual comfort (designated discomfort glare) and relative visibility resulting from studies in other nations, for example: Netherlands (6), Great Britain (7, 8, 9), and West Germany (10).

OUTDOOR FULL-SCALE EVALUATION OF RELATIVE VISUAL COMFORT

This paper presents the use of the Guth evaluator for rating the relative visual comfort of roadway lighting systems. Outdoor, full-scale, field testing is involved as differentiated from ratings based on a previously described computation method (5).

Figure 1 shows relative visual comfort ratings for similar roadway lighting systems derived by two different methods (5, 17).

The evaluator ratings A and B pertain to different driver-observer positions along a roadway lighting system (Fig. 2). The ratings have been derived from a recent selective analysis of data produced by two years of outdoor field testing of a lighting system (13) at Hendersonville, N.C. (Figs. 2 and 3). Observer data selected on the basis of a BCD "population study," involving 50 people, which has been recently conducted in the Photometric Laboratory at Hendersonville, is described later in this paper. The evaluator used was developed by S.K. Guth and J. McNelis of Nela Park (17). The computed ratings are based on use of a method (5) of rating the relative visual comfort of lighting systems which has been presented during the past year (5, 11, 12). In this instance the luminaire spacing is 105 ft staggered. The visual comfort ratings shown in Figure 1 are relative to the motorist-observer sensation which would be at

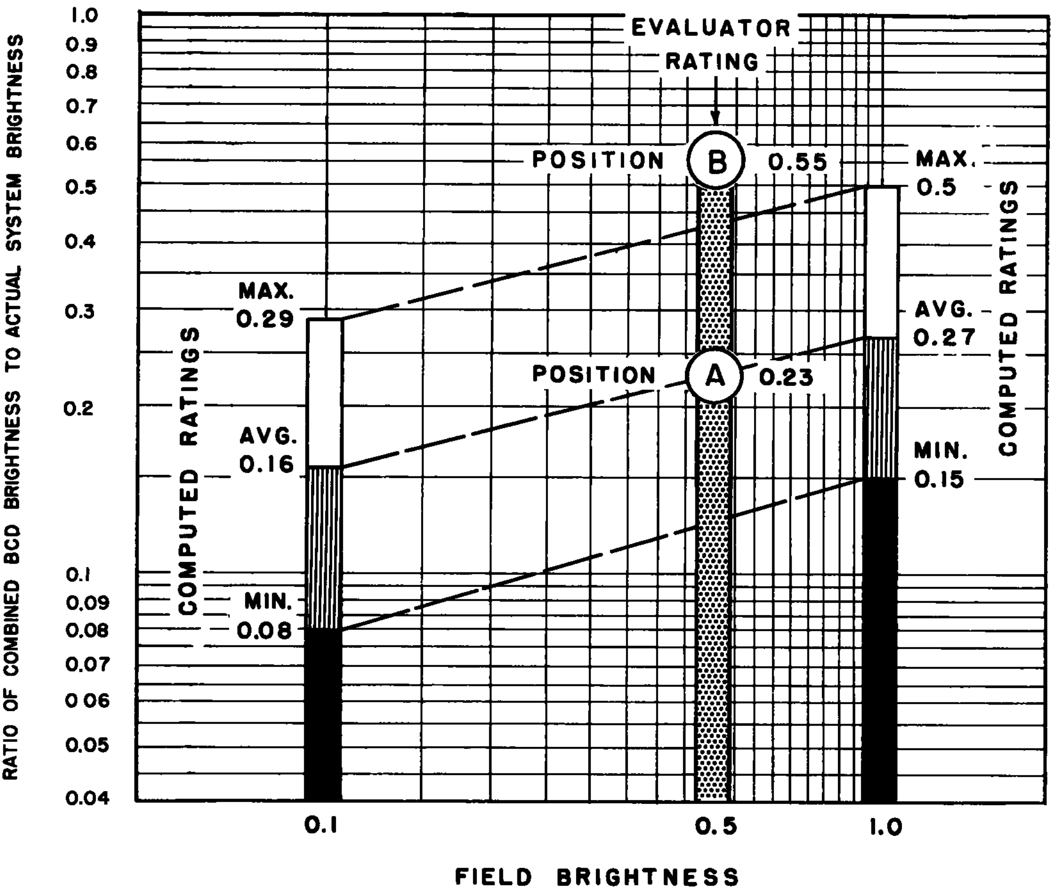


Figure 1. Evaluator relative visual comfort ratings for selected driver-observer at Position A and Position B on the roadway shown in Figure 2 are presented for comparison with computed ratings (5). These ratings for similar roadway lighting systems are of similar magnitude even though different BCD methods are involved. Note increase in computed relative comfort ratings with increase in field brightness.

BCD, the borderline between comfort and discomfort, for the system of luminaires and the lighted roadway (5), or the lighted roadway only (17), as differentiated in Table I and its footnotes.

The evaluator (17) BCD brightness, $\overline{B}_L$, is on the observer's line of sight and excludes the combined brightness of the system luminaires. The computed average combined BCD brightness Avg $\Sigma \overline{B}$, includes the BCD brightness of the luminaires off the driver's line of sight, in representative pole bracket locations. However, there is similarity in the magnitude of the rating ratios produced by the two different methods (5, 17).

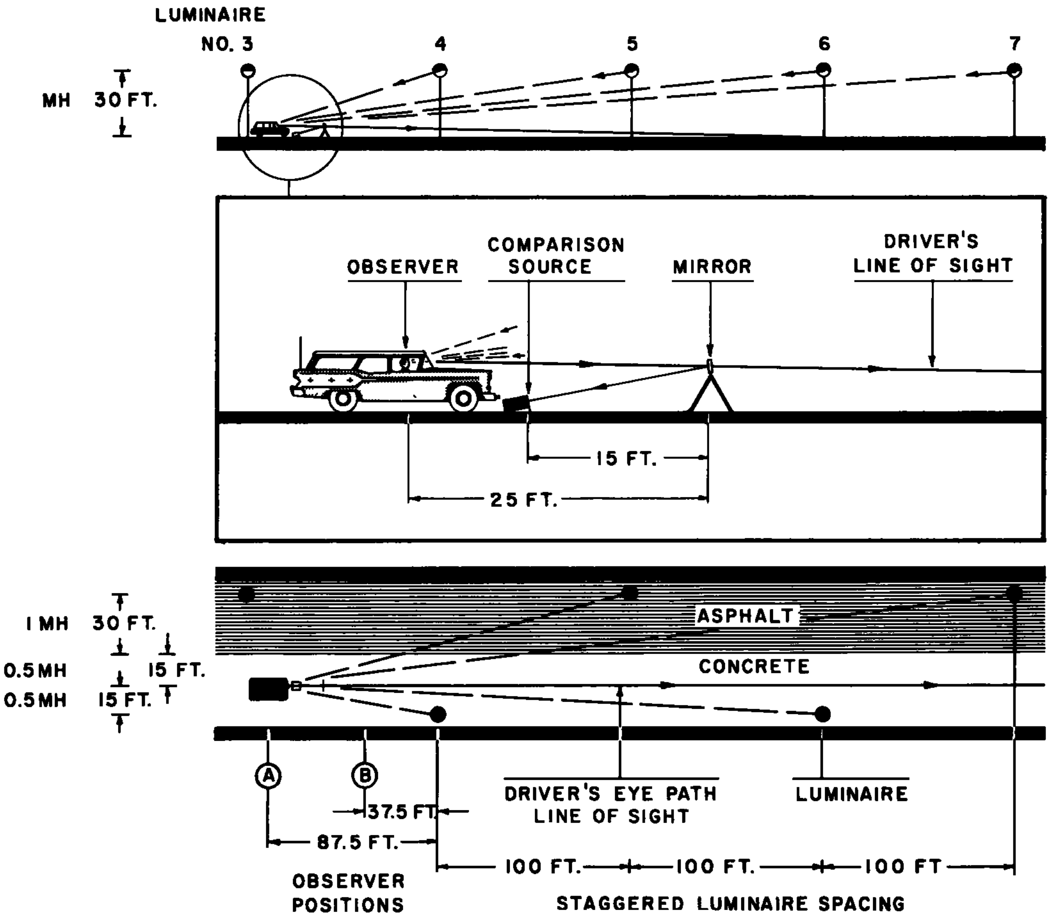


Figure 2. Evaluator observer positions A and B shown with respect to the layout of full-scale roadway lighting system tested. Center inset shows dimensional position of evaluator components; that is, comparison brightness and source, mirror, with respect to observer sitting in a representative automobile.

EVALUATOR RATING METHOD

The evaluator rating at each motorist-observer viewing position is:

$$\text{Evaluator Ratio at each position} = \frac{\Sigma \bar{B}_L}{\Sigma B_c}$$

in which $\Sigma \bar{B}$ is the brightness of a source on the observer's line of sight which is at BCD sensation brightness with respect to the lighted roadway background excluding luminaires (fL) and ΣB is the brightness of a comparison source on observer's line of sight which produces sensation equivalent to the combined brightness of the system of luminaires (fL).

The field brightness in this instance is assumed to be approximately the same as the average pavement brightness along the observer's path, 0.5 footlambert.

The lighting systems for both the evaluator and computed ratings include the same type of standard production luminaires. The luminaires are typical of those which have been installed and are in use in many portions of the United States and Canada. The projected area of the luminaire sources viewed from each observer position is the same as for a type of luminaire which has been widely used for mercury lamps. Equipped with 15,000-lumen multiple-filament lamps, the luminaires are at 30-ft mounting height. The transverse distances are also the same for both systems, as indicated in Figure 2.

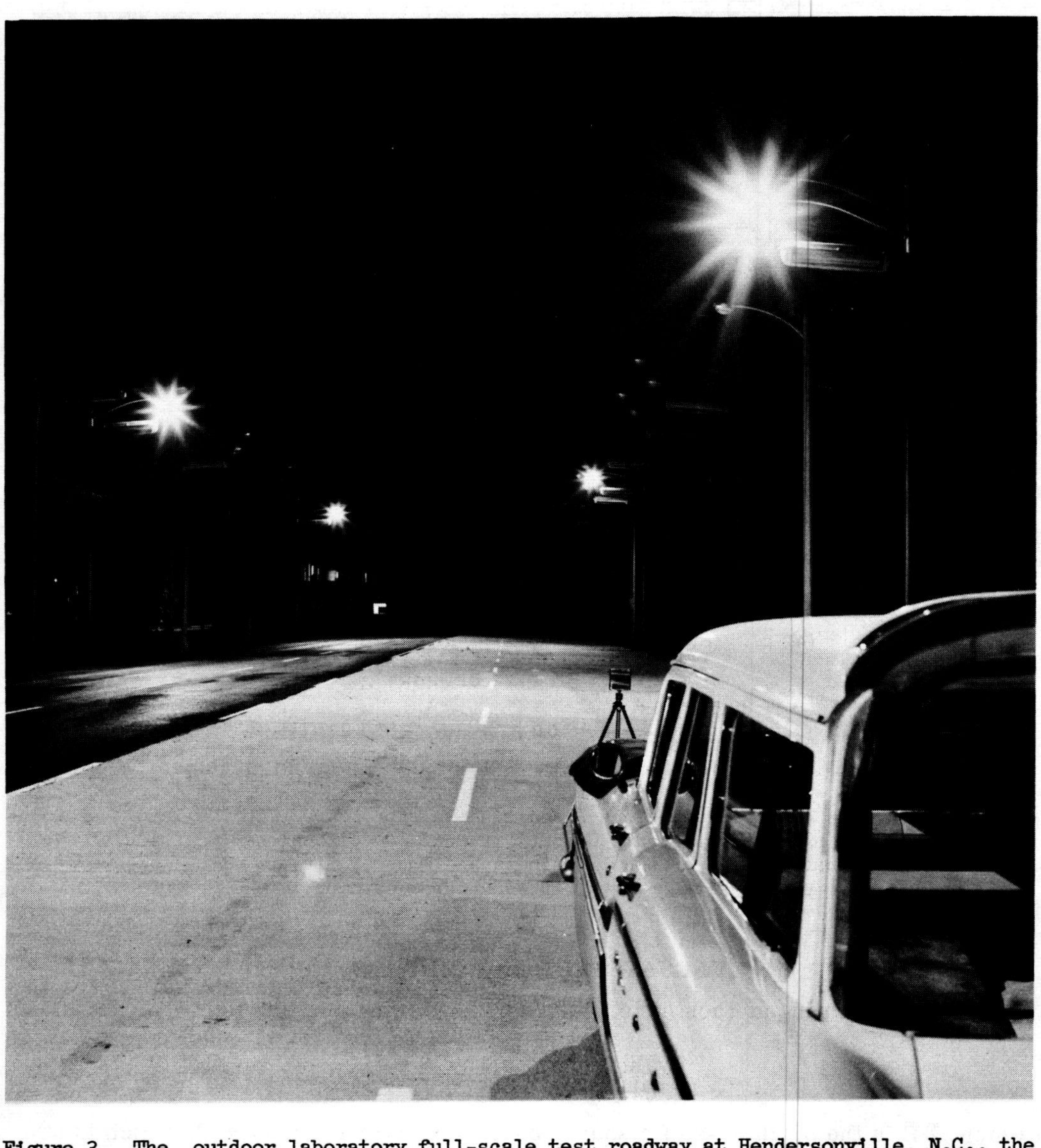


Figure 3. The outdoor laboratory full-scale test roadway at Hendersonville, N.C., the system luminaires, the evaluator mirror in front, and the representative automobile in which the driver-observer is seated while rating relative visual comfort of the lighting system with the aid of the Guth evaluator is shown.

COMPUTED RATING METHOD

The computed rating (5) at each of the several successive motorist-observer viewing positions, and for each field brightness condition is :

$$\begin{array}{l}\text{Computed Ratio}\\ \text{at each position}\end{array} = \begin{array}{l}\Sigma\,\overline{B}\\ \Sigma\,\overline{B}\end{array}$$

in which $\Sigma \bar{B}$ is the combined brightness of system luminaires which would be at BCD sensation when mounted on the pole brackets with a specified field brightness including that of the pavement (fL) and ΣB is the combined actual brightness of the system luminaires (fL).

A computed rating (designated avg) is the arithmetic average of the ratings (5) over a cycle of 14 observer positions for a longitudinal distance twice the luminaire spacing. Use of the geometric mean of these ratios instead of the arithmetic would change the mean from 0.16 to 0.15 for F = 0.1 footlambert, and from 0.27 to 0.25 for F = 1.0 footlambert. The arithmetic mean or average is being used for computed ratings (5) and geometric mean for evaluator ratings (17).

TABLE 1

EVALUATOR VERSUS COMPUTED METHOD AND RESULTING DIFFERENCE IN DATA FOR SYSTEM OF ROADWAY LIGHTING LUMINAIRES WITH 15,000-LUMEN MULTIPLE-FILAMENT LAMPS (ALL BRIGHTNESS DATA ARE IN FOOTLAMBERTS)

		BCD Brightness		Brightness of System Luminaires		Rating Rates	
Type of Rating	Field Brightness	Avg. ΣB^1 for System of Luminaires Not on Line of Sight	$\bar{B}_L$ [2] Excluding Luminaires	Avg. ΣB^3 Actual Luminaires Combined	B_L [4] in Terms of Line of Sight	$\bar{B}_L/B_L$ Line of Sight	Avg. of $(\Sigma\bar{B}/\Sigma B)$
Computed average of ratios for 14 positions	F = 0.1	3500		24,600			0.16
	F = 1.0	5900		24,600			0.27
Evaluator Full-scale Test Rating	F = 0.5						
Position A			830		3630	0.23	
Position B			1120		2020	0.55	
Simulator Studies in Photometric Laboratory 1959	F = 0.1		417				
	F = 0.5		640[5]				
	F = 1.0		777				

[1]Average combined brightness of system luminaires which would be at BCD sensation when mounted in pole bracket location 30 feet above roadway for two assumed field brightness conditions which include the pavement brightness.
[2]Geometric average of observed brightness of evaluator source which is at BCD sensation on the observer's line of sight toward pavement. Luminaires are excluded. Evaluator source size is 0.000025 steradian.
[3]Average combined actual brightness of lighting system luminaires.
[4]Geometric average brightness of evaluator comparison source on line of sight which produces sensation equivalent to that of the combined effect of lighting system luminaires.
[5]Extrapolation from Figure 11. Source size is 0.000032 steradian.

The computed ratings are shown for two field brightness conditions (5), F = 0.1 footlambert and F = 1.0 footlambert. The field brightness is the average integrated brightness in the driver's field of view including the brightness of the pavement and objects thereon and nearby. The average brightness of the lighted pavement directly in front of the observer is approximately 0.5 footlambert. If, in addition, the integrated brightness of the luminaire sources is included, the over-all field brightness is appreciably increased.

The development of an instrument for the measurement of the combined brightness in the driver's field of view has been actively solicited during the past several years. Fry (28) has developed such a device for an I.E.R.I. project. B.S. Pritchard, of the Ohio State University Institute for Research in Vision, completed the instrumentation for field use. This meter has been used in studies conducted by Blackwell (22). It is hoped that the measured field brightness of the luminaires and pavement for the lighting system shown in Figure 2 will be reported (22) during the 1959 I.E.S. Technical Conference. It is hoped that future footlambert field brightness measurements will be made from the driver's eye position in a typical automobile so as to include conditions such as top of auto windshield cutoff, etc. (5, 11, 12, 14, 16).

The lighting system for the computed ratings spaces the luminaires 105 ft staggered (3.5 MH) instead of the 100 ft staggered arrangement used for evaluator ratings. The multiple of 0.5 MH spacing facilitates computation, using the method presented in detail (5).

The data used for computation was derived from laboratory studies by Putnam-Bower (19) and Putnam-Faucett (20).

The size ω of each luminaire source is computed for the installed pole bracket locations and representative observer viewing positions (5). Expressed in terms of steradians, the size ω is the visual solid angle subtended at the observer's eye position by the projected area of each luminaire source. These data include the driver-observer position at longitudinal distance of 3.0 MH. In this instance, the top of auto windshield cutoff (5) is assumed to occur at longitudinal distance of less than 3.0 MH to correlate with evaluator Position A (Fig. 2).

At the latter position, 87.5 ft in front of luminaire No. 4, on the driver's right, this

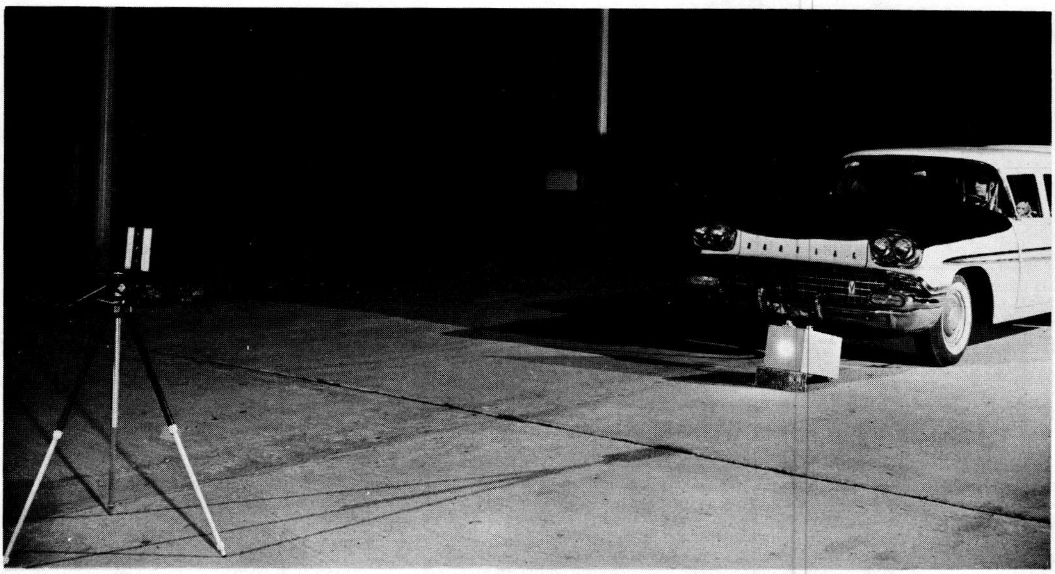


Figure 4. Front oblique view showing test conditions with evaluator BCD or comparison source near front of automobile, mirror at left, and observer in driver position.

source was in full view of all observers. This was at least partially due to the lean-forward posture assumed by the observers in order to use the headrest supported by the auto steering wheel (Fig. 5).

USING THE EVALUATOR FOR RATING ROADWAY LIGHTING

Using the evaluator for rating the visual comfort of roadway lighting has involved setups similar to those shown in Figure 2 to Figure 6, inclusive.

The brightness of the evaluator source is reflected in the small mirror directly in line with the observer's line of sight; that is, toward the middle of the concrete pavement background, about 1 deg below the horizontal.

The brightness of the evaluator source (Fig. 4) is adjusted by the observer, using the variac remote control (Fig. 5). A flashing sequence is used for the evaluator source, 1 sec on, 1 sec off, with a 2-sec break every 10 sec. During the off interval, between each exposure, the evaluator source is lighted to stand-by brightness adjusted to be equivalent to that of the pavement background. The size of the evaluator source is 0.000025 steradian.

BCD EVALUATION

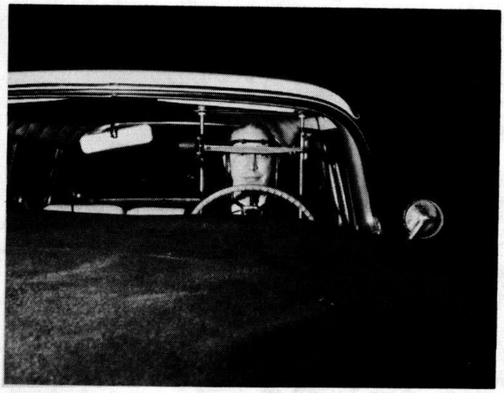
With the movable shield remaining in the down position to shield out the luminaires, as shown in the upper portion of Figure 6, the observer adjusts the brightness, $\bar{B}_L$, of the evaluator source until it is judged to produce the BCD sensation at the borderline between comfort and discomfort. The source brightness reflection is viewed against the field brightness in front of the observer comprising the lighted pavement, some unlighted pavement, roadside, sky areas, and the translucent shield areas as indicated in Figure 3 and the upper portion of Figure 6.

The BCD test results are given in Table I. For observer position A, $\bar{B}_L$ = 830 foot-lamberts on the driver's line of sight.

Figure 5. Observer R.K. Drake shows how the Guth evaluator source brightness is remotely controlled from the driver position in an automobile. During the relative visual comfort rating of a roadway lighting system, the shield portion of the headrest assembly is first down steadily for appraisal of the BCD-brightness on his line of sight with luminaires excluded from view. This is followed by automatic rotation of the shield up and down to alternately expose the observer-driver's eyes to the impact sensation judged to be equivalent to the combined brightness of the system luminaires.

The average pavement brightness along the driver's path is approximately 0.5 foot-lambert. It is believed that these measurements will be consistent with measurements made by B.S. Pritchard, using his 10-mm aperture brightness meter, during studies (22) conducted by H.R. Blackwell and sponsored by I.E.R.I.

Evaluator tests have been made to determine the approximate difference in BCD brightness, $\bar{B}_L$, when the shield is raised to expose the observer's eyes to the steady, combined brightness of the luminaires, in addition to the pavement brightness. This increases the integrated average field brightness. Nine tests by seven observers indicate that, under this condition, the BCD brightness, $\bar{B}_L$, on the observer's line of



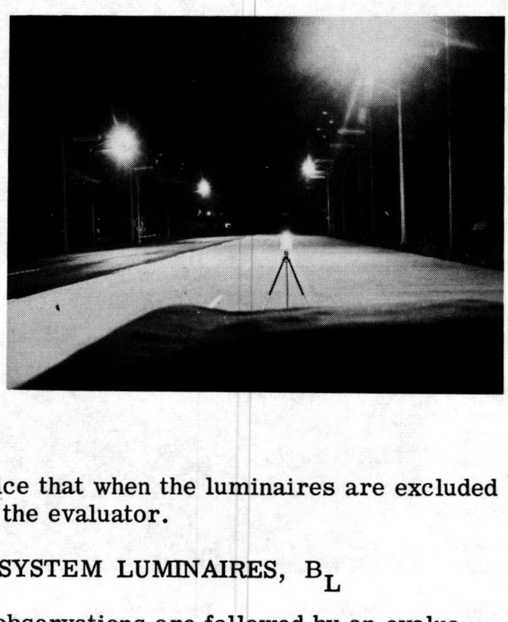


Figure 6. Upper left photo shows observer in test automobile with evaluator headrest shielded in the down position for appraisal of the BCD brightness. The resultant cutoff of luminaires and observer's field of view is shown in the upper right photo. The lower photo shows the driver-observer's view when the shield portion of the evaluator headrest is rotated upward to expose the observer's eyes to the combined brightness of the system luminaires. For evaluation of system luminaire brightness, the upper and lower test conditions are alternated automatically. The observer adjusts the brightness of the comparison source reflected in a mirror on the line of sight for an impact sensation judged to be equivalent to the combined brightness of the luminaires.

sight is increased; that is, of the order of twice that when the luminaires are excluded from view. The latter is customary in using the evaluator.

EVALUATING BRIGHTNESS OF SYSTEM LUMINAIRES, B_L

To complete each evaluator test the BCD observations are followed by an evaluation of the combined brightness of the system luminaires in terms of the equivalent impact sensation brightness of the evaluator comparison source. The shield is rotated upward to expose the brightness of the luminaires to observer view. At this time the comparison source is off, illuminated only to stand-by brightness. Then the shield is lowered to cut off the luminaires without intercepting the aforementioned portion of the field brightness, including the pavement brightness. At this time the evaluator comparison source is turned on.

The alternate exposure of the observer's eyes to the combined brightness of the luminaires followed by the brightness of the comparison source, B_L, is automatic, by a cam which alternately energizes power, to motor operation of the shield, then to the source. The alternate exposures of the system luminaires and the comparison source are of 1-sec duration, separated by 1-sec intervals. Three exposures of each, luminaires, and then comparison source, is followed by a 5-sec period for observer evaluation of the sensations and then re-adjusting the brightness of the comparison source. The observer adjusts the brightness of the comparison source until it produces the same impact sensation (17, 18) or feeling as does the combined brightness of the luminaires.

During the evaluation of both the BCD brightness, $\bar{B}_L$, and luminaire system brightness, B_L, the observers keep their eyes fixated on the comparison source aperture. The observer is allowed as many cycles as desired to make an appraisal. During each test five observations are made of each, the BCD brightness, $\bar{B}_L$, and brightness of the comparison source, B_L, equivalent to that of the luminaires. Comparison of the geometric mean of the brightness appraisals which are both based on observations on the line of sight provides the ratio $\bar{B}_L/B_L$ for the relative comfort rating at each position.

Evaluator data for Position A presented in Figure 1, Figure 2, and Table 1, is based on 240 observations by four observers selected as described later. Each of the six ratings made by each selected observer involved ten observations. The mean BCD brightness, $\bar{B}_L$, is 813 footlamberts. The comparison brightness, B_L, with the system luminaires in view, is 3630. This provides a ratio $\bar{B}_L/B_L$ rating of 0.23. The same rating is obtained by taking the geometric mean of the ratio ratings for each of the four observers. For Position B in Figure 2, the same selected observers were used, but a total of 80 observers and eight ratings are available for the geometric mean.

The selection of observer data on the basis of an average "population study" or BCD brightness evaluation conducted in the laboratory does not necessarily mean that the observers will also make the most authentic evaluator comparison rating for the combined brightness of the system luminaires. However, "population study" provides valuable guidance.

Also of interest in this respect is the fact that the outdoor full-scale evaluator studies at Position A for the same filament lamp lighting system (Fig. 2) have involved 21 observers, including those selected. The 21 observers have made 48 relative comfort ratings, or 480 observations. Based on all of this data comprising a larger number of random observers making an unequal number of tests, the geometric mean relative comfort rating is 0.19. This may be compared with the rating of 0.23 by the four selected observers (Fig. 1).

FEATURES OF EVALUATOR

The evaluator may be used to demonstrate and provide better understanding of the fundamentals involved in improving relative visual comfort. A driver-observer sitting in an automobile readily adjusts the brightness of the flashing comparison source to the BCD, borderline sensation between comfort and discomfort. By changing the lighting, the driver can observe and readily appreciate the fact that the BCD brightness for a roadway lighting system increases with appreciable higher field brightness, including the brightness of the pavement background against which the flashing comparison source is being viewed.

For example, one observer test with the luminaires shielded from view showed an increase in BCD brightness, $\bar{B}_L$, by 4.4:1 when the average foot-candles on the pavement were increased in the ratio of 4.6:1. Inasmuch as the higher level of illumination was obtained with opposite spacing and the lower foot-candle level with the staggered spacing in Figure 2, the pavement brightness did not increase proportionately.

An increase in field brightness improves the relative visual comfort ratio unless accompanied by a corresponding increase in the combined brightness of the system luminaires. The latter may be increased within the limits of the relative comfort ratio without decreasing the relative visual comfort. The evaluator demonstrates that progress involves higher brightness at or near the pavement level with lower brightness up at the luminaire mountings.

Because it provides guidance and aids comprehension of visual comfort principles and ratings for the roadway lighting which makes night driving easy and pleasant for millions of drivers, this evaluator is a very valuable development.

Numerical ratings for the visual comfort quality of roadway lighting are an impelling objective which fully justifies such night work. It is an essential step toward increasing the night use of the public investment in automotive transportation facilities.

INDOOR BCD EVALUATIONS

To provide calibration data on the outside observers, an indoor population study-type exploration of judgments of BCD sensation was made (24). Using a five-sided environmental chamber (Fig. 7), painted flat white on the inside, BCD evaluations were made by means of the Guth evaluator. This meter and its use will not be discussed as it has been described previously and in the literature (17). The test procedure included at least two separate settings for each observer. Each setting consisted of five valid BCD evaluations, at each of three background field brightnesses, with appropriate waiting periods for observer eye adaptation. For example, a minimum 10-min eye adaptation period was first required prior to any readings being taken.

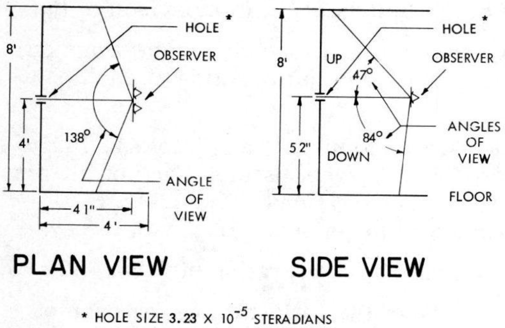


Figure 7. Dimensional sketch of indoor environmental chamber showing vertical and horizontal angles of view to observers. Light sources to provide background brightness were located to either side of observer at about eye level and were shielded from observer.

Although the environmental chamber consisted of ½ an 8-ft cube, very uniform brightness over the visual field (Fig. 8) was possible by the particular lighting system employed. The Guth evaluator was placed behind the opening (source size = 3.23×10^{-5} steradians) in the environmental chamber. This source size was a constant throughout the test and represented the same visual angle at 41 in. as the 2⅝-in. diameter evaluator source size viewed at approximately 41 ft outdoors.

Instructions to the observers on the conduct of the test were read to each person so that all received the same information. Test equipment was set up in a large, black room assuring the necessary quiet and disturbance-free atmosphere required by this type of psychological study. Only the experimenter and the observer were in the room at the time of the observations, with the experimenter located at the rear of the booth (Fig. 9).

Figure 8. View of observer (center) in the environmental chamber looking at the flashing spot of light (at upper left). Hand control is located to the observer's right, and the brightness meter for making brightness calibrations is at the upper right.

Observers consisted of an all-white population of 52 people, 22 female and 30 male. Age range for the group was 40 yr; latitude of birthplace range, 21 deg in north latitude. During the course of the study, three sets of data (all female)

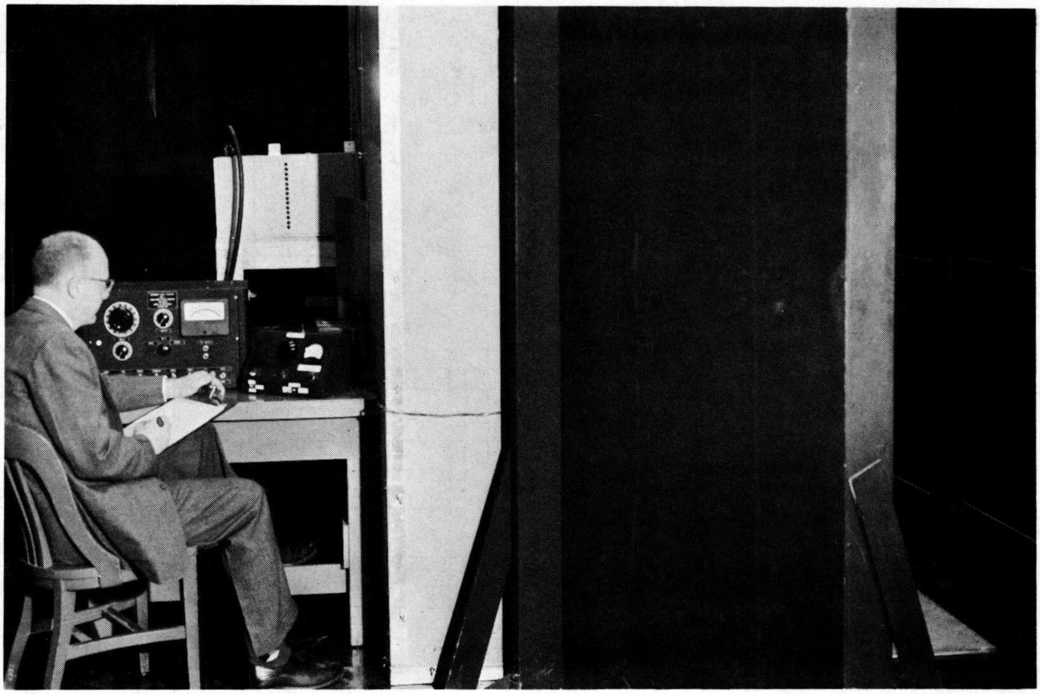


Figure 9. View of read of environmental chamber (center) showing baffled entrance to chamber (extreme right) and control area at left. Guth discomfort glare evaluator light source box is above and to the right of the large control cabinet.

had to be eliminated because of either inconsistent or insufficient data. Thus, results which follow have been drawn from a total of 49 reliable sets of data. Educational background of observers varied from high school to those meeting the Master's requirement at a college level. Observers represented management, office, and factory workers in a typical industrial organization, and were selected to cover a wide range of age (Fig. 10), latitude of birthplace (Fig. 10C), educational background, and sex (Fig. 10B). The degree of success is evidenced in the preceding illustrations. Infor-

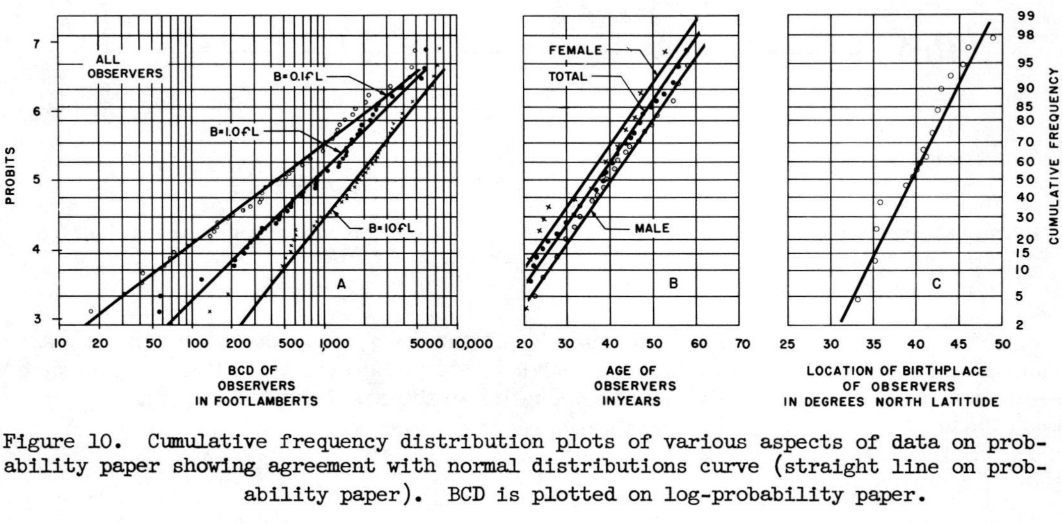


Figure 10. Cumulative frequency distribution plots of various aspects of data on probability paper showing agreement with normal distributions curve (straight line on probability paper). BCD is plotted on log-probability paper.

mation on the latitude of birthplace has been included to see if this had any correlation with BCD. In making this attempted correlation, it was assumed that early environment plays a large part in any cause and effect relationship that might exist between BCD and latitude. In addition to the selection of observers by any of the aforementioned requirements, all observers participating in the full-scale outdoor night observations of comfort were obviously included.

RESULTS

Figure 11 shows the excellent agreement between the results of this work compared with those obtained by previous investigations (20, 27). A detailed statistical analysis

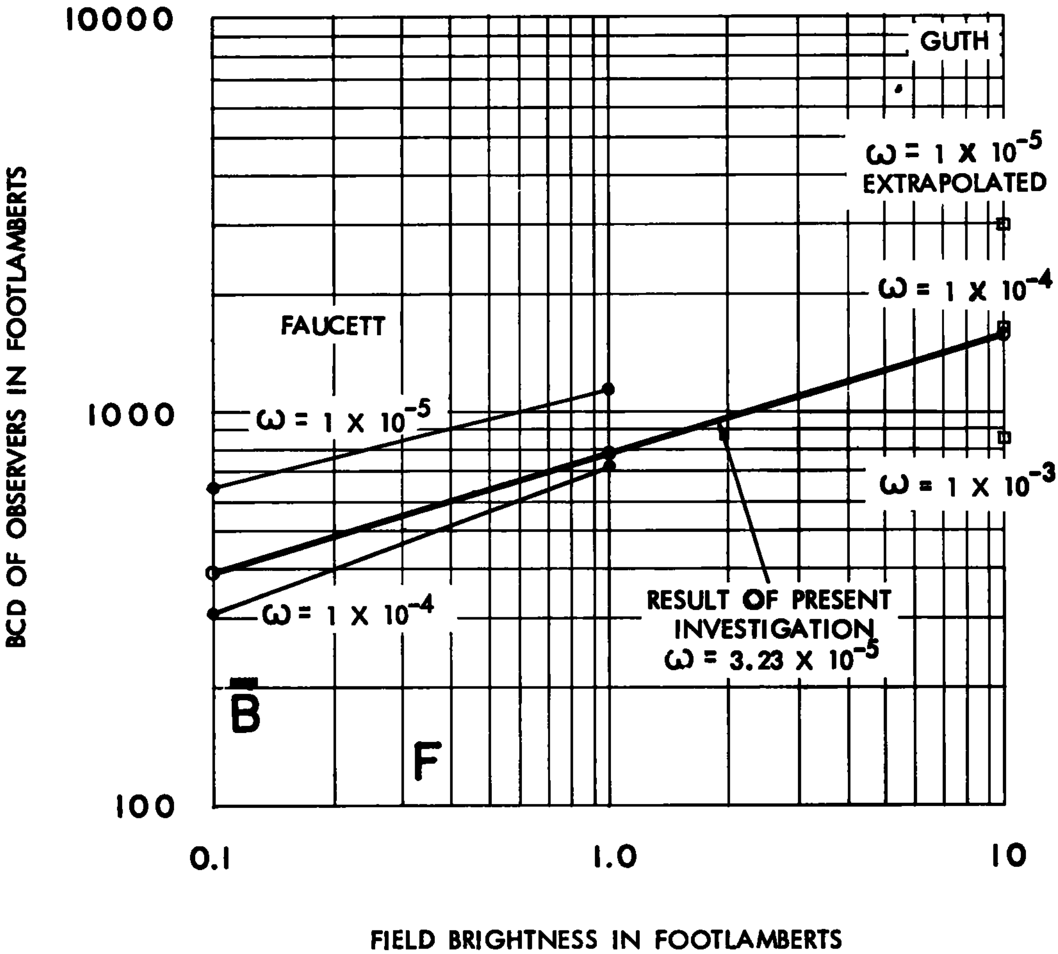


Figure 11. Results of BCD versus field brightness found in the present investigation as compared with results of previous work by Faucett and Guth.

(25) of the data has been included in Table 2. It should be noted that although the arithmetical averages have been included in Table 2, the geometric mean (G_m) values have been used throughout the analysis. The equation of the resulting curve (Fig. 11) has been found to be:

$$\bar{B} = 800F^{0.30}$$

TABLE 2

(A) SUMMARY OF ALL STATISTICAL DATA SHOWING RESULTS AT THREE FIELD BRIGHTNESS FOR MALE, FEMALE, AND TOTAL OBSERVERS

	Field Brightness									North	
	Female			Male			Total			Latitude	Age
Basic BCD Data	0.1	1.0	10.0	0.1	1.0	10.0	0.1	1.0	10.0	(deg)	(yr)
No. of observers	19	19	19	30	30	30	49	49	49	49	49
Arithmetical averages	1410	1940	2780	850	1230	2340	1090	1480	2510	39	38.2
Geometric mean Gm	538	892	1630	347	692	1550	417	777	1590	39	36.4
Minimum (Gm values)	30	55	132	9	15	37	9	15	37	28	21
Maximum (Gm values)	4760	6000	7940	5900	5660	7310	5900	6000	7940	49	61
Range (Gm values)	4730	5945	7808	5891	5645	7273	5891	5985	7903	21	40
Median (Gm values)	509	861	1700	398	858	1915	436	861	1840	37.5	39
Standard deviation, σ (Gm values)	1685	2140	2680	1222	1241	1831	1470	1660	2200	4	10.7
Coefficient of variation, V (Gm values) (%)	314	240	164	352	179	118	352	213	138	10	29.4
Mode										39.4	39.5
Calculated correlation data: BCD vs. north latitude Product moment correlation Coefficient, r							-0.083				
Calculated correlation data: BCD vs. age Product moment correlation Coefficient, r							+0.12				

(B) DATA SIMILAR TO TABLE 2A EXCEPT USING "LOG BCD" AS THE BASIC QUANTITY IN ALL CALCULATIONS

		Female 0.1	Female 1.0	Female 10.0	Male 0.1	Male 1.0	Male 10.0	Total 0.1	Total 1.0	Total 10.0
Geometric mean G_M	BCD	457	813	1520	269	576	1350	331	661	1410
	Log BCD	2.66	2.91	3.18	2.43	2.76	3.13	2.52	2.82	3.15
Standard deviation, σ (log BCD)		0.64	0.55	0.47	0.66	0.54	0.48	0.66	0.55	0.48
Coefficient of variation V (log BCD) (%)		24	10	15	26	20	15	26	20	15
Standard error of mean $s_{\bar{x}}$ (log BCD)		0.15	0.13	0.11	0.12	0.10	0.09	0.10	0.08	0.07

Figure 12 has, in addition to the curve for the total population, separate curves for (a) all male observers, (b) all female observers, and (c) the eleven outside nighttime observers. As can be seen, at the lower field brightnesses there is a greater difference between male and female observers than at the 10 fL level, with women having a higher BCD value than men by approximately 50 percent. A study of Table 2 will show that, although women have approximately the same range of BCD, the standard deviation is greater at all three field brightnesses. These results would indicate a difference in BCD sensation between males and females, particularly at low field brightness, but perhaps a larger population sample would have brought the curves closer to that of the total population.

Although eleven observers volunteered for the outdoor night observations and a large quantity of data have been collected on various observers and street lighting systems, observers 6, 7, 8, and 9 (Fig. 12) have been selected for the purpose of this paper. The geometric mean of the BCD sensations of these four observers at 0.1 and 1.0 foot-

TABLE 3

A DETAILED SUMMARY OF STATISTICAL DATA ON BCD VERSUS NORTH LATITUDE

	NORTH LATITUDE				
	25°-29.9°	30°-34.9°	35°-39.9°	40°-44.9°	45°-45.9°
Observers	1	3	22	20	3
BCD Minimum	793	436	30	9	94
BCD Maximum	793	5900	4490	4760	2050
BCD Range	0	5464	4460	4751	1956
BCD Median	793	1410	334	555	148
BCD Gm			364	381	
σ			1074	1553	
V			295%	408%	

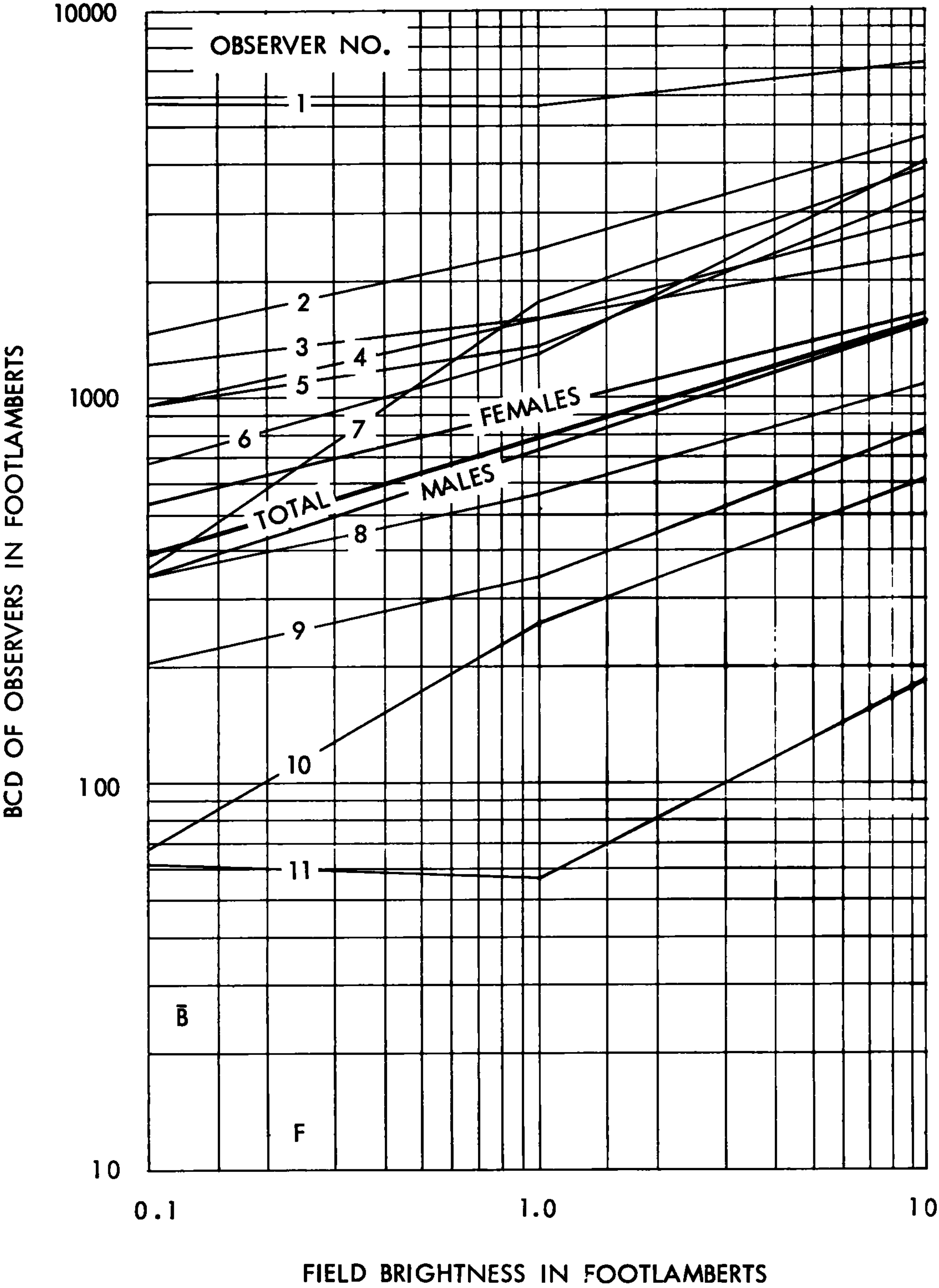


Figure 12. Curves for data on BCD versus field brightness for all male, female and outside nighttime observers, as well as total observer population.

lambert field brightness falls very close to that of the total population. Data on the other observers have been included so that the range and individual variations can be noted.

CORRELATION TESTS

A correlation test for the relationship of BCD versus latitude of birth gave negative results. Results are summarized in Table 2 and Figure 10C. The negative product moment correlation coefficient (26) of -0.083 indicates practically no correlation. The negative sign of "r" would seem to indicate that whatever little correlation exists is such that a decrease in north latitude is associated with an increase in BCD sensation. Table 3 gives results of a statistical analysis of the two principal latitude groupings (of which a sufficient number of observers were available). This also indicates very little difference between the two groups of data. A scatter diagram also showed no definite pattern. Figure 10C, which shows a plot of the data on probability paper, indicates a normal distribution of observers over the range of north latitude covered by the data.

A correlation test for the relationship of BCD versus age was also tried. This also gave negative results. Results are summarized in Table 2 and Figure 10B. The positive product moment correlation coefficient of 0.12 indicates practically no correlation. The positive sign of "r", however, would seem to indicate that whatever little correlation exists is such that an increase in age is associated with an increase in BCD sensation. A scatter diagram also showed no definite pattern. Figure 10B, which shows a plot of the data on probability paper, indicates that a better choice of observers (particularly female) with regard to age could have been made, although male and total populations indicate a normal distribution of observers over most of the age range. The problem, of course, is the inability of finding older men and women within the avenues of approach that were made available in the process of selecting possible observers. It should also be noted that the greatest number of drop-outs or rejects from the originally selected observer group were from the female group.

For the variation of individual BCD sensations at any field brightness, see Table 2 for the statistical data and Figure 10A for a plot of the data on probability paper. All three curves indicate a right-skewed distribution with the values for the geometric mean and median, all below a BCD value of 2000 fL. Readings, however, trailed off to almost 8000 fL.

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