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A MODIFIED FORMULA FOR CALCULATING THE DISABILITY GLARE EFFECT FROM STREET LIGHTING LANTERNS

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CONTENTS

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ABSTRACT

Holladay and Stiles suggested that the effect of a glare source on contrast sensitivity is the same as that of a luminous veil whose luminance is $G = \frac{kE}{\theta^n}$ ftL., where E is the glare illumination in the plane of the pupil of the eye in lm/ft^2, θ is the angle of the glare source from the line of sight in degrees and n and k are constants. Later research has however shown that the relationship is more complex and that if this formula is to be used n and k should be treated as variables.

The aim of the present investigation was to determine representative values of n and k to use in estimating disability glare from street lighting lanterns. On the basis of the new results and those from an earlier investigation it is suggested that n should be taken as 2.2 and k as $(0.2A + 5.8)\ \pi$ where A is the age of the observer in years.

1. INTRODUCTION

The effects produced by glaring lights in an observer's field of view are usually divided into discomfort effects and disability effects. This report is concerned with disability glare (i.e. glare which impairs the ability of an observer to see objects) in lighted streets. The problem was investigated by the method developed by Holladay[1] and Stiles[2]. The main aim of the research was to check on the adequacy, for street lighting investigations, of the Holladay-Stiles formula for calculating the effect of glare on contrast sensitivity.

When an object is just discernible against its background the difference in luminance (i.e. brightness) between the object and background is called the threshold luminance difference (Δ). This quantity (Δ) is changed when a glare source is introduced into the field of view: it can also be changed by altering the background luminance. It is therefore possible to find an equivalent background luminance (β) which requires the same threshold luminance difference in the absence of glare as is required with the real background luminance (B) in the presence of glare. Except when glare is very low β is greater than B. Thus the effect of a glare source on contrast sensitivity can be likened to the effect of superimposing a luminous veil, of luminance G, over the object and its background, where $G = \beta - B$ i.e. G is the difference between the equivalent background luminance and the real background luminance.

Holladay and Stiles found that, with a uniform background luminance and a uniform veiling luminance, G could be expressed by the formula

$$G = \frac{kE}{\theta^n} \quad \text{ft L.}$$

where E = illumination in lm/ft^2 produced by the glare source in the plane of the pupil of the eye

θ = the angle, in degrees, between the glare source and line of sight

and k and n were constants of approximately 10π and 2 respectively.

From an investigation carried out at the Laboratory[3, 4] indications were obtained that the phenomenon is more complex than might be supposed from the Holladay-Stiles treatment. Firstly by using complex instead of uniform backgrounds the experimentally determined value of G was shown to vary with the distribution of luminance over the rest of the surrounding field in a way not allowed for by the formula. Secondly it was found that under identical experimental conditions different observers gave different values of G and that to account for this different values of k had to be taken for different observers[4], k increasing with age; n on the other hand could be taken as having the same value for all observers. Thirdly it was found that with a given observer and a given background configuration the variation of G with θ appeared to be slightly different from that indicated by the Holladay-Stiles formula: thus different values of n and k had to be used for different ranges of θ .

A further experiment has now been carried out with a complex background representing a lighted road and with a group of observers whose ages fell within a ten-year band. One aim of the experiment was to verify the existence of what, for brevity, will be called the dependence of n upon θ and to obtain information about it which might lead to a better understanding of disability glare. A second and severely practical aim was to find the most suitable values of n and k to employ for street lighting purposes if the Holladay-Stiles formula were to continue to be employed.

2. SUBJECTS

Six male subjects each took part in six experimental sessions, over a period of two weeks. Their ages ranged from 35 to 45 years (mean age 41 years). None wore spectacles and each had a visual acuity of 6/6 or better.

3. APPARATUS

3.1 The road scene and test object

A diagram of the apparatus is shown in Fig. 1. The viewed scene was a perspective representation of a 30 ft wide roadway, with 20 ft wide verges and 20 ft high vertical surrounds. To the subject it appeared that he was 10 ft in from the nearside kerb and that he had an eye height of 4 ft. The luminances of the verge and background were 1/2 and 1/7 respectively of the road luminance; the sky was black. A circular test spot which subtended 0.35^{o} at the eye was seen, by reflection in a thin glass slide, superimposed on the roadway at an apparent distance of 300 ft.

Luminance adjustments of the road scene and the test spot were made by altering the voltages applied to the lamps. The light from both the spot and the roadway passed through similar green filters so as to minimise colour changes resulting from the voltage adjustments.

3.2 The glare sources

Four glare sources were positioned vertically above the test spot in the black surround. As each glare source had to provide the glare effect normally produced by an installation of street lanterns the glare illuminations were chosen so that each source would produce approximately equal values of veiling glare.

In practice the glare effect from street lanterns has a significant effect on visibility only in the darker areas of road. In the apparatus the road surface had a uniform luminance; therefore in order to obtain a reasonably large glare effect the illumination from each source was about ten times greater than that from a single street lantern viewed from the same angle.

3.3 Viewing conditions

The apparatus was enclosed in a box. The subject viewed the scene monocularly; the measurements of angles and of illuminations were more precise than if both eyes had been used. In some visual experiments artificial stops are used in front of the eye so as to remove effects due to variations in the size of the subject's pupil. In this experiment the natural pupil was used so that variations in pupil size would enter into the glare effect as they normally do in the real situation.

A sighting device built into the apparatus was used to find the correct eye position at the beginning of each experimental session. Using a head rest and an adjustable chin rest the subject's head was held in the correct position.

4. EXPERIMENTAL PROCEDURE

4.1 Calibrations

A telephotometer was used to obtain the luminances of the test spot and background as a function of the applied lamp voltages. The glare illumination at the eye was obtained by measuring the luminance of a piece of calibrated transmission opal placed at the eye position.

To measure the angles between each glare source and the test spot a camera was mounted with its lens positioned so that the front nodal point was located at the position of the pupil of the observer's eye: a photograph was taken of the glare sources, test spot, and a calibrated scale. The required angles were obtained from distances measured on the photographic negative.

Investigation showed that the measurements of angles with this method were accurate to within approximately 5 minutes of arc.

The mean values of the glare angles and illuminations at the eye were found from periodic checks to be:-

(i) $\theta = 1.7^{o}$, $E = 0.038$ lumens/ft^2
(ii) $\theta = 3.8^{o}$, $E = 0.36$ " "
(iii) $\theta = 9.4^{o}$, $E = 3.2$ " "
(iv) $\theta = 18.2^{o}$, $E = 12.6$ " "

4.2 Test procedure

The experiment was, of course, conducted in a dark room. The subject first spent 10 minutes looking at the road scene with the road surface luminance set at 0.1 ftL. to allow his eye to adapt to the general level of luminance used.

Two types of observation were made: observations in the absence of glare at several different road luminances and observations in the presence of glare at the single chosen level of road luminance (0.3 ftL.).

The observations without glare were made as follows. The road luminance was set to the required value. Then the experimenter slowly increased the test spot voltage until the subject said that he could just distinguish the circular shape of the spot. This voltage was recorded. The voltage was rapidly increased and then slowly decreased until the subject could just not see the shape of the spot; this voltage was also recorded. Several road luminances were presented in an ascending order and the above procedure repeated. The geometric mean of each pair of recorded voltages was used to obtain the test spot luminance.

The observations in the presence of glare were made as follows. The road luminance was set to 0.3 ftL. and one glare source switched on. During the 2 minutes required for the illumination from the glare source to reach a steady value it was masked from the subject by a mechanical shutter, and the subject was directed to look at the roadway. When the glare source was revealed the test spot voltages for the just detectable and just not detectable conditions were found, and used, as before. This procedure was carried out for the four glare sources whose order of presentation was varied between sessions. A complete session lasted approximately 30 minutes.

5. RESULTS

As the subjects' contrast sensitivities were found to vary from session to session the results of each subject-session were treated separately. From the results for each non-glare sequence a graph was plotted of the threshold luminance difference (Δ) against the background luminance (B) (see Fig. 9). From this graph the equivalent background luminance (β) was read for the value of Δ obtained with glare. By design each glare source had roughly the same value of β and so was read from the same part of the graph. As a result only a small range of readings was needed to plot the graph of Δ against B. The equivalent veiling glare was calculated as

$$G = \beta - B_O$$

where B_O was the real background luminance in the glare situations.

The Holladay-Stiles formula may be written as

$$\log \frac{G}{E} = \log k - n \log \theta$$

The experimentally determined values of $\log \frac{G}{E}$ have been plotted against $\log \theta$ in Figs. 2-7. If the Holladay-Stiles formula held exactly the points would lie on straight lines (different for each subject) with a slope of $-n$ and an intercept of $\log k$ on the $\log \frac{G}{E}$ axis.

Regression lines fitted to the experimental points are shown in Figs. 2-7. They represent the best fits of the Holladay-Stiles formula to the data, over the complete range of angles studied. The derived values of n and k are shown in Table 2. These values are discussed later.

It will be seen that in all cases the experimental points in Figs. 2-7 would fit better on to curves, concave upwards. This indicates that the variation of $\frac{G}{E}$ with θ is more complex than is suggested by the Holladay-Stiles formula.

Improved accuracy in the calculation of G could be obtained in practical applications by choosing different values of n and k appropriate to the different ranges of θ. Successive points in each of the Figs. 2-7 were joined by straight lines and the slopes and intercepts of these lines used to provide values of n and k for each angular range. These are given in Table 1. It should be noted that whereas the value of k would have a physical significance if the Holladay-Stiles formula were exact (k would be the value of $\frac{G}{E}$ at $\theta = 1^{o}$) this is not true for values of k derived for individual ranges, (except for a small range about $\theta = 1^{o}$). In these cases k has only a mathematical significance.

Statistical tests showed that the variation of n with θ was significant at the 0.1% confidence level.

Finally, to obtain a single value for n and for k appropriate to the complete range of θ involved (i.e. 1^{o}-20^{o}) a single regression line was fitted to a plot of all the meaned values of log $\frac{G}{E}$ against log θ (Fig. 8). From this line n and k were estimated as 2.20 and 15.1 π respectively.

Estimates of $\frac{G}{E}$ were made from the glare formula in which (i) the best single values of n and k were used, and (ii) values of n and k appropriate to the angular range were used. Table 3 shows that the differences in the estimates obtained by the two methods were approximately $\pm$ 20% which was less than differences in the values of $\frac{G}{E}$ found for the different subjects.

6. DISCUSSION

One of the main aims of the experiment was to study variations in n produced by varying the glare angle θ. The results in Table 1 provide further evidence of the tendency noted previously [4, 5] for the effective value of n to fall as θ increases.

The other aim was to obtain estimates of the best single values of n and k to insert in the Holladay-Stiles formula when using it in street lighting investigations. The assumption has been made that the appropriate range of glare angles to cover and the appropriate distribution of background luminance to use are those used in the experiment. From a regression analysis of the combined data from all subjects the values $n = 2.2$ and $k = 15.1\,\pi$ were obtained as mean values for the complete range of angles studied. In the next paragraph these values are compared with those obtained by Fisher[3] in his second experiment.

For observers of the same age as in the present experiment Fisher obtained the values $n = 2.3$ and $k = 14\,\pi$. His range of angles was considerably smaller (1^{o}-4^{o}) than in the present experiment; by a consideration of the observed variation of n and k with angle θ it would be expected that both n and k from the present experiment would be smaller than Fisher's values. The difference in the two values of n was therefore in the expected direction but the difference in k was not.

That the difference in k goes the wrong way is not surprising in view of the large variations in k shown in Tables 1 and 2. It is believed that these variations are due to real differences between subjects of the same age as well as to the large experimental error inherent in investigations of this type. It must be concluded that there is, at present, no adequate evidence to depart from the estimates of k obtained by Fisher.

7. CONCLUSIONS

It is concluded that when the Holladay-Stiles formula

$$G = \frac{kE}{\theta^n}$$

is used in street lighting investigations the value of n should be taken as 2.2 rather than 2.3 as was suggested by the results of an earlier experiment[3]. For k the value found by Fisher for observers aged A years

$$k = (0.2A + 5.8)\pi$$

should be retained until further evidence is available.

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TABLE 1

Derived values of n and k for the three ranges of the glare angle θ

Observer	Age (years)	Angular Range					
		$\theta = 1.7^o$-3.8^o		$\theta = 3.8^o$-9.4^o		$\theta = 9.4^o$-18.2^o	
		n	k	n	k	n	k
A	45	2.59	13.43 π	2.30	9.06 π	1.53	1.63 π
B	44	2.51	19.63 π	2.09	11.25 π	1.75	6.56 π
C	41	2.55	22.75 π	2.29	16.14 π	1.78	5.18 π
D	35	2.71	16.07 π	1.83	3.36 π	1.54	1.75 π
E	41	2.75	46.88 π	2.25	23.82 π	1.33	3.09 π
F	39	2.76	34.59 π	2.42	22.08 π	1.62	3.66 π
* Mean values for the group of observers		2.65	23.21 π	2.20	11.95 π	1.59	3.21 π

TABLE 2

Derived values of n and k for the complete range of glare angles

Observer	n	k
A	2.21	9.40 π
B	2.05	12.88 π
C	2.25	17.36 π
D	2.18	8.67 π
E	2.19	28.05 π
F	2.34	23.47 π
* Mean values for the group of observers	2.20	15.13 π

* Arithmetic mean for 'n' but geometric mean for k (as k is calculated as an intercept = log k ∴ mean intercept = a.m. of log k).

TABLE 3

$\frac{G}{E}$ calculated from Holladay-Stiles glare formula

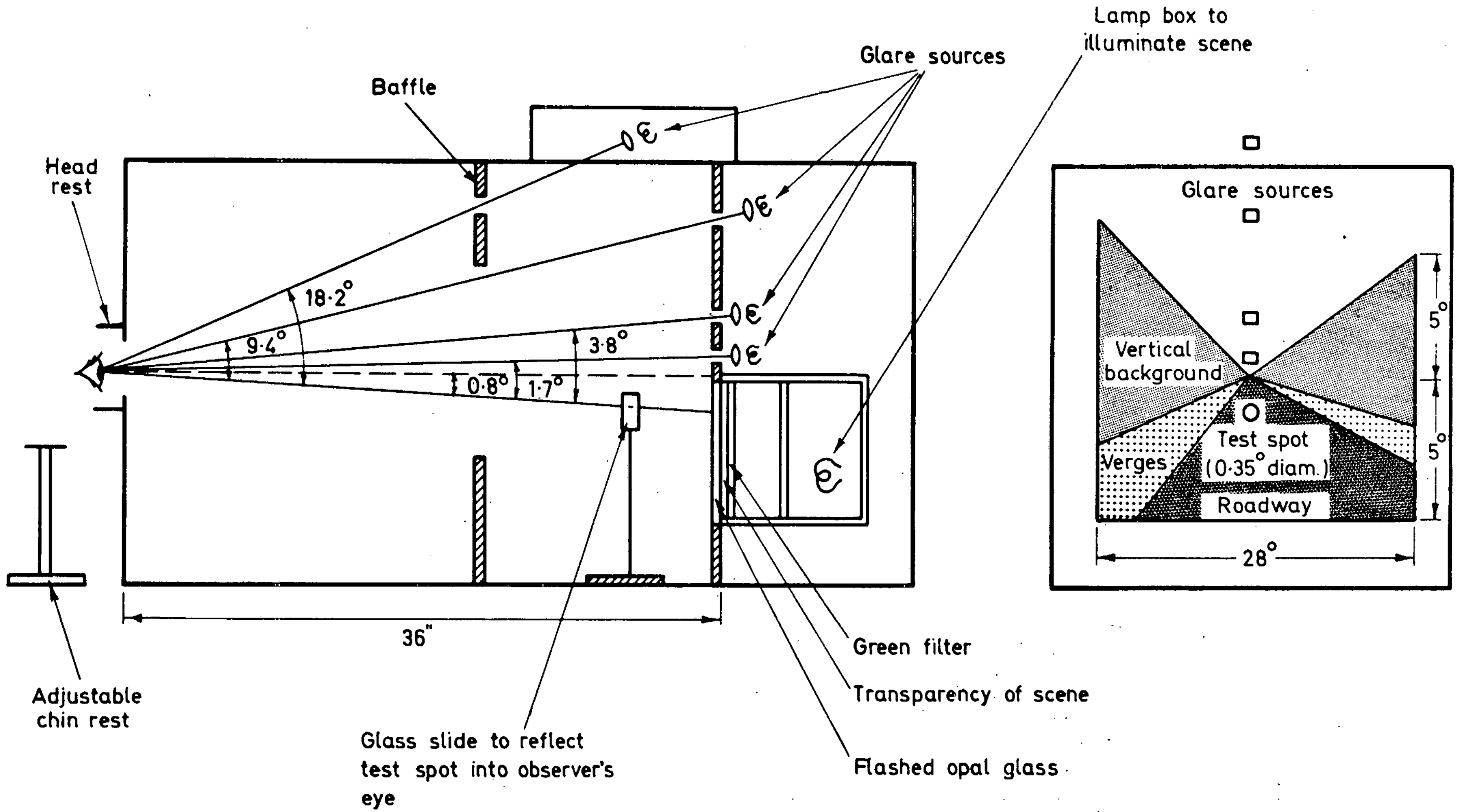
(i) using the best single values for n and k ,
(ii) using the values of n and k appropriate to the angular range

Glare angle (θ) in degrees	(i) $\frac{G}{E}$ calculated from $\frac{G}{E} = \frac{15.13\pi}{\theta^{2.2}}$	(ii) $\frac{G}{E}$ calculated from formula appropriate to angular range		Percentage difference* in $\frac{G}{E}$ calculated by the two methods
1.7°	14.83	17.90	n = 2.65	+ 20
2.75°	5.14	5.01		- 2
3.8°	2.52	2.12	k = 23.21π	- 15
3.8°	2.52	1.99	n = 2.20	- 21
6.6°	0.75	0.59		- 21
9.4°	0.34	0.27	k = 11.95π	- 20
9.4°	0.34	0.29	n = 1.59	- 14
13.8°	0.15	0.16		+ 6
18.2°	0.08	0.10	k = 3.21π	+ 25

* Percentage difference calculated as $\frac{b - a}{a}$ x 100% where

(a) $= \frac{G}{E}$ from column 2 of table

(b) $= \frac{G}{E}$ " " 3 " "



(a) CROSS SECTION

(b) VIEWED SCENE

Fig. 1. GLARE APPARATUS

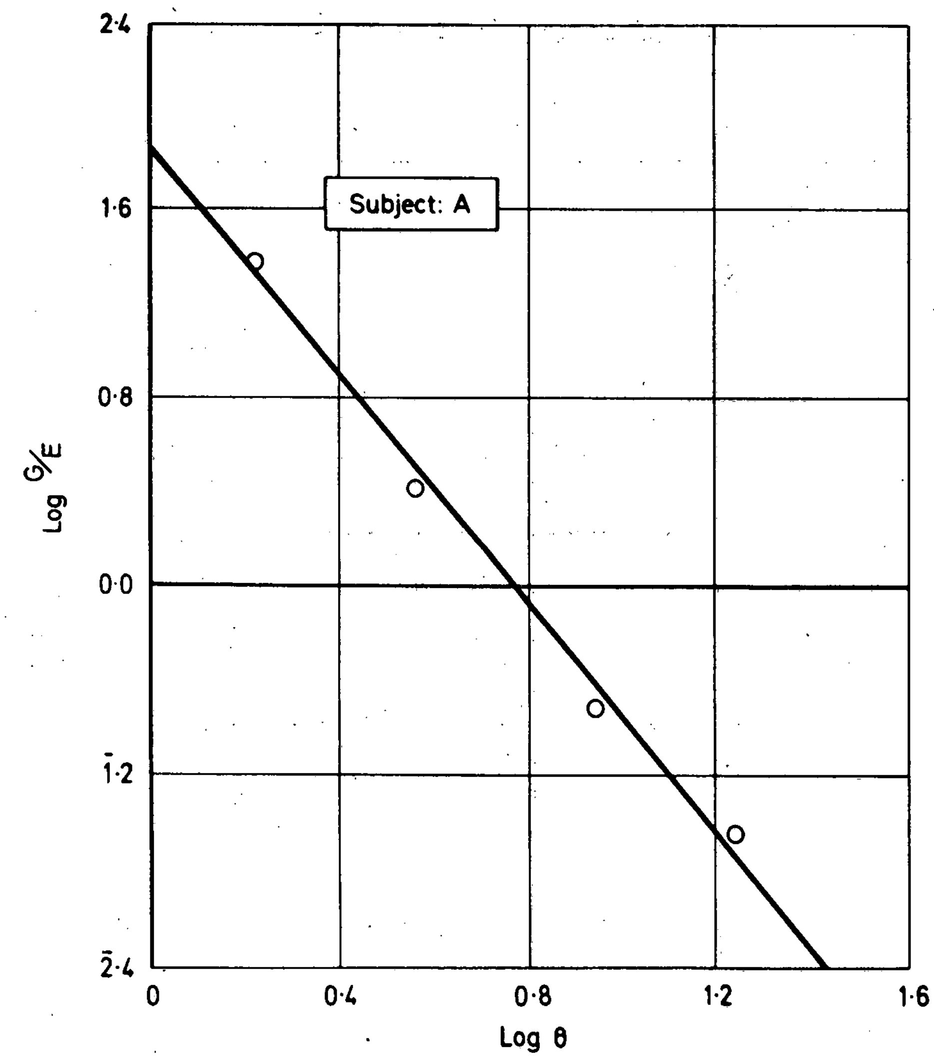


Fig. 2. PLOT OF LOG G/E AGAINST LOG θ

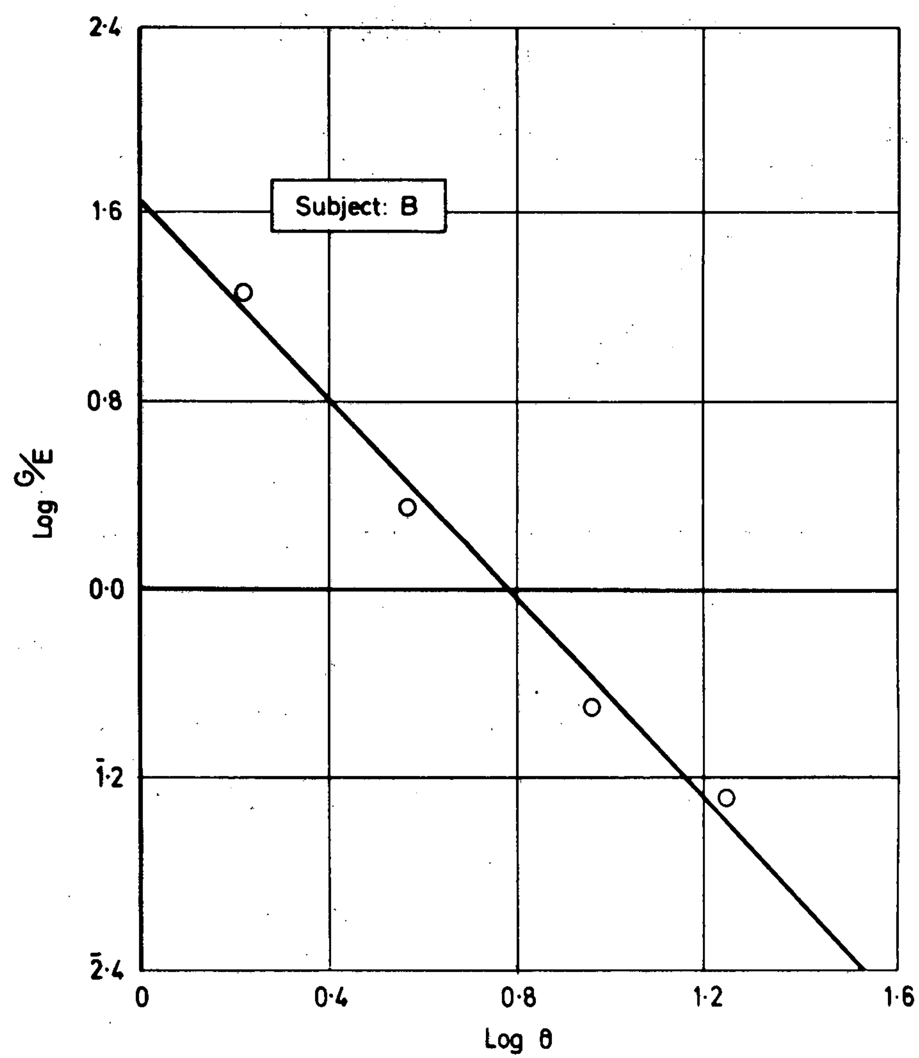


Fig. 3. PLOT OF LOG G/E AGAINST LOG θ

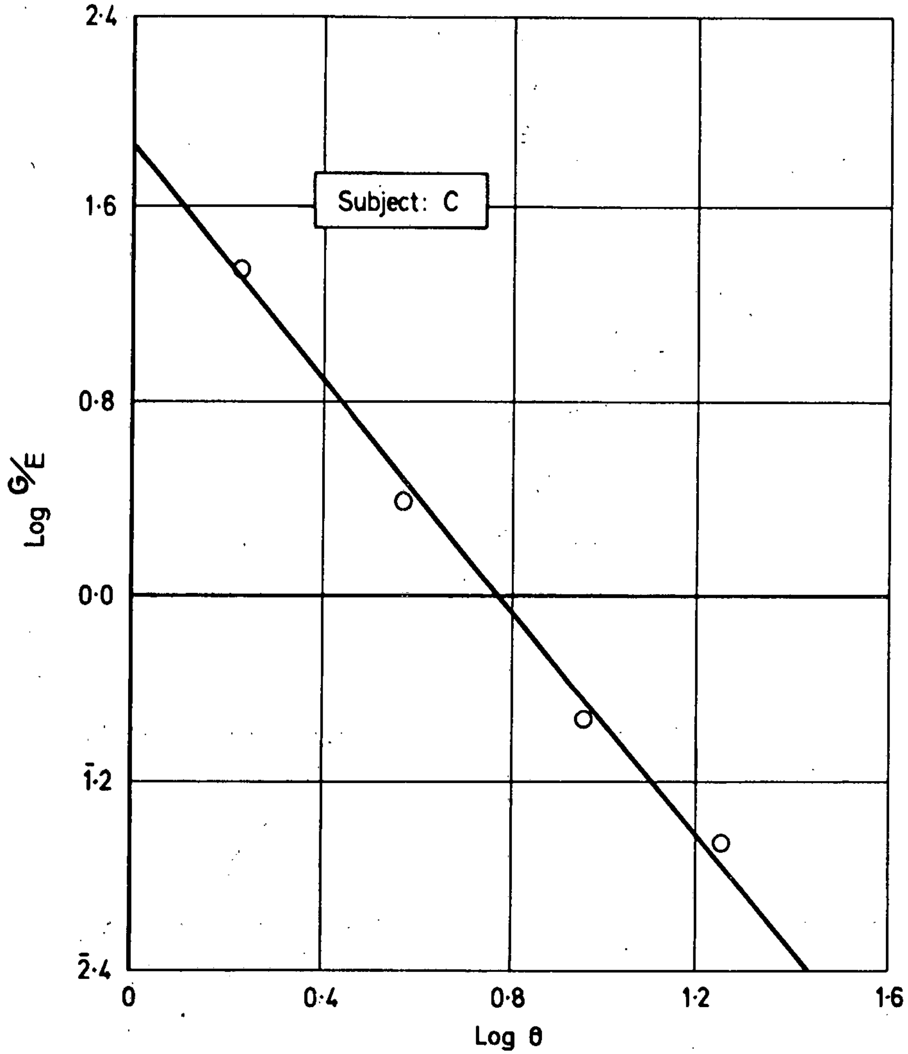


Fig. 4. PLOT OF LOG G/E AGAINST LOG θ

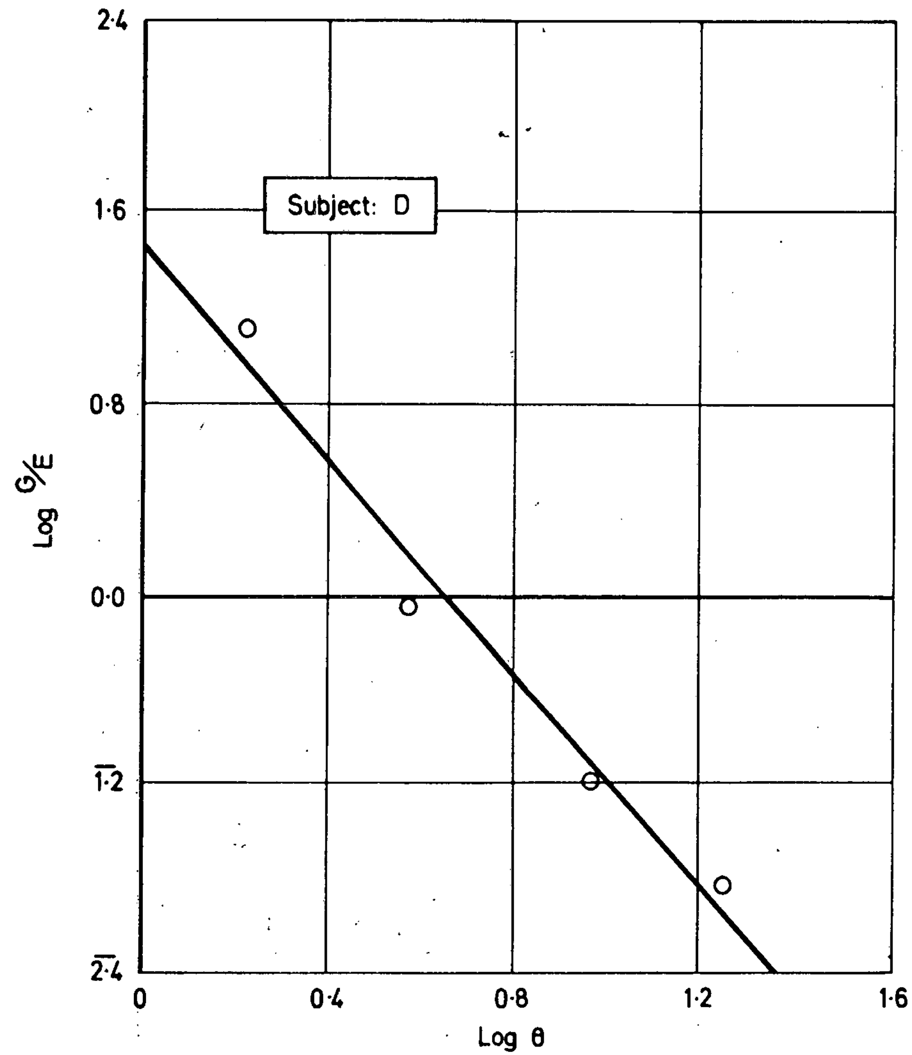


Fig. 5. PLOT OF LOG G/E AGAINST LOG θ

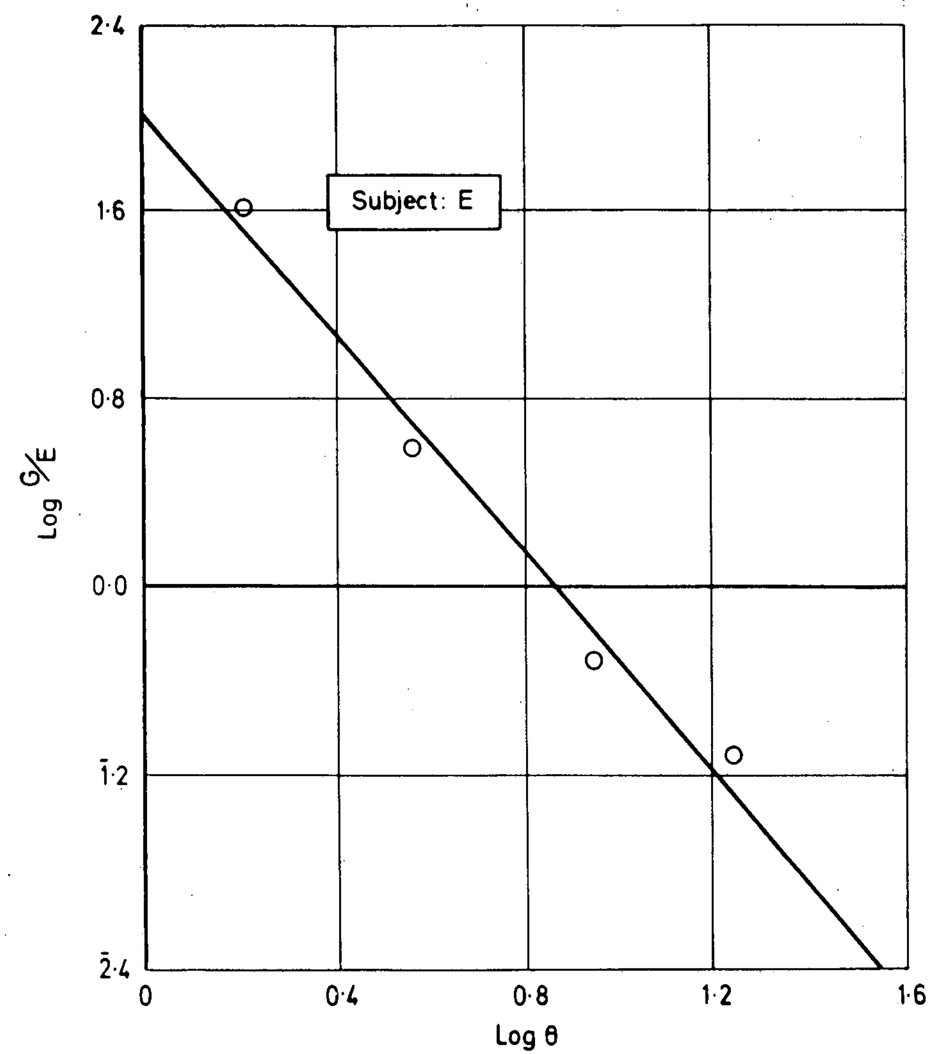


Fig. 6. PLOT OF LOG G/E AGAINST LOG θ

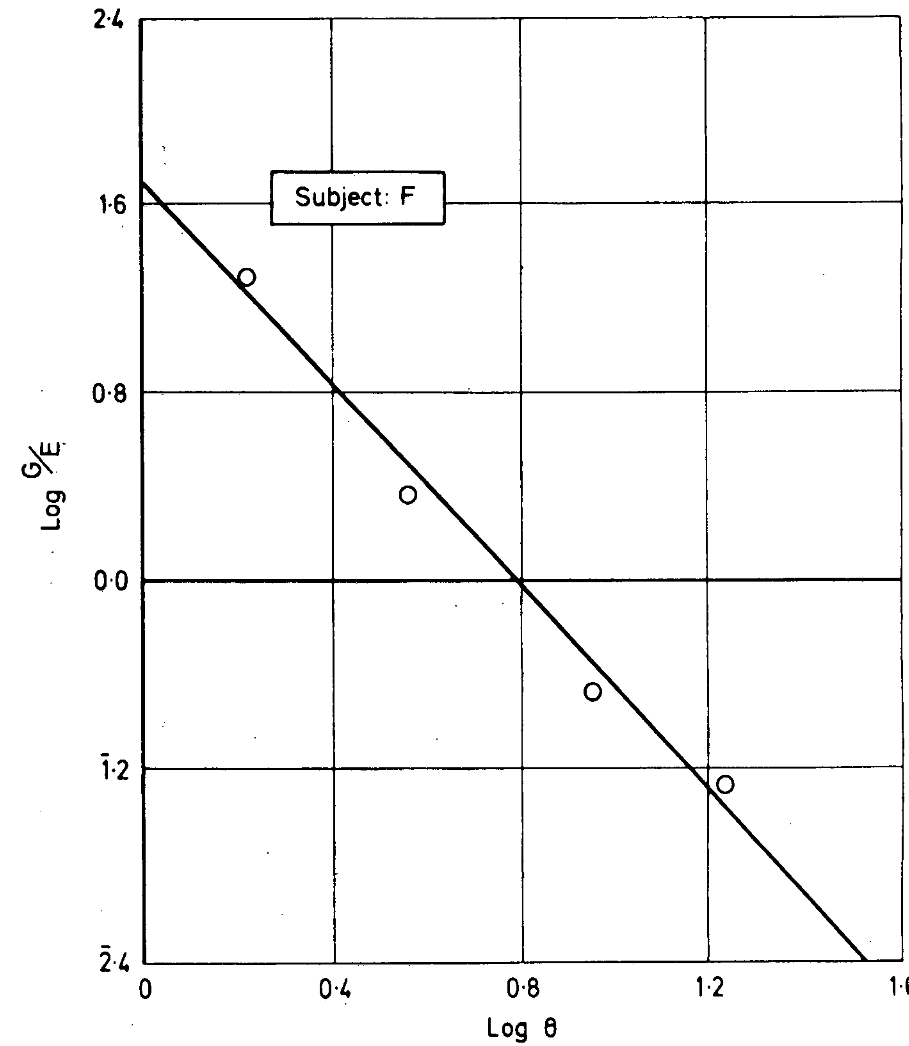


Fig. 7. PLOT OF LOG G/E AGAINST LOG θ

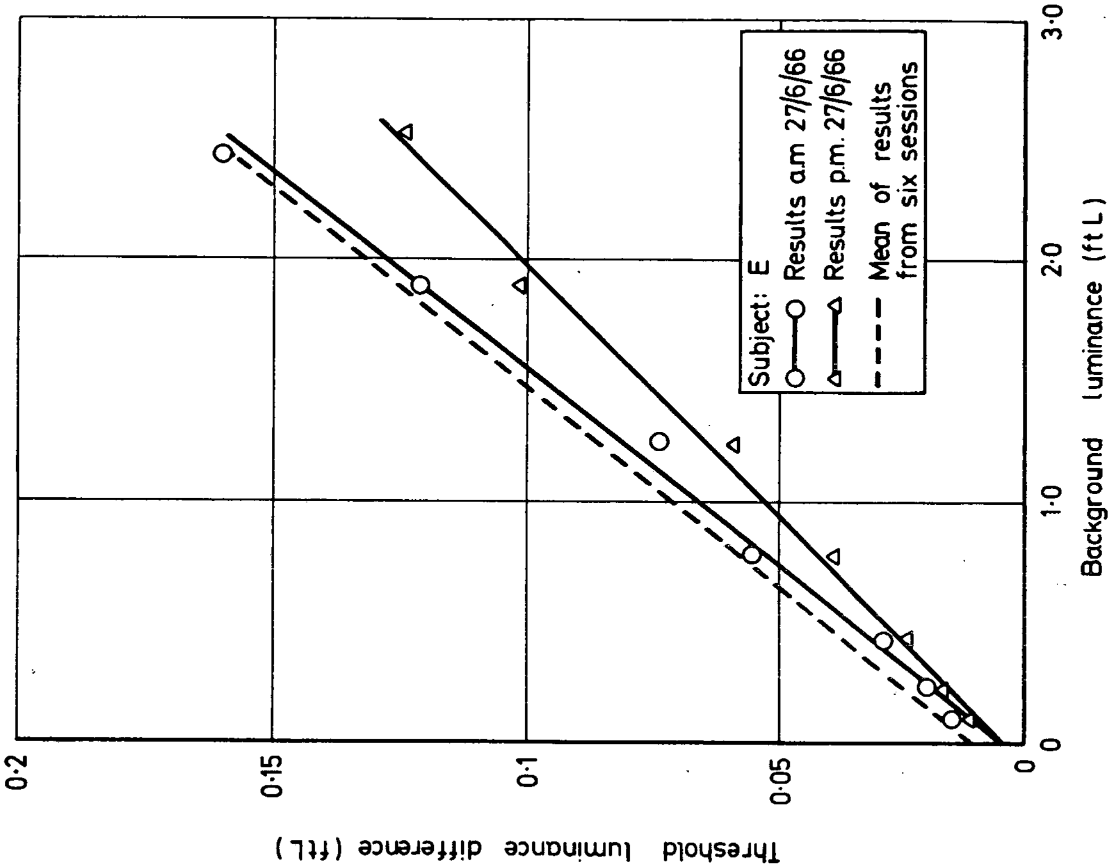


Fig. 9. THRESHOLD LUMINANCE DIFFERENCE / BACKGROUND LUMINANCE

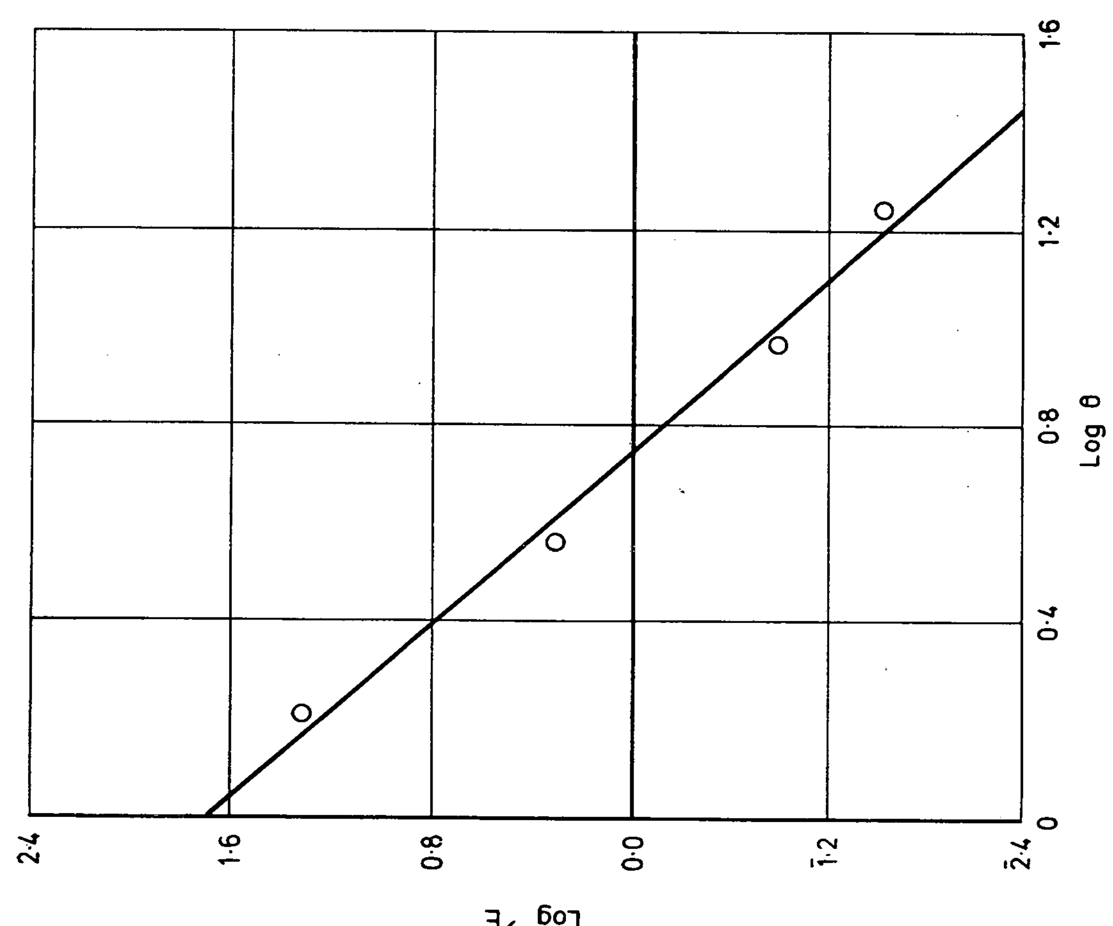


Fig. 8. MEAN VALUE OF LOG G/E FROM ALL SUBJECTS/LOG θ

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