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CERTAIN FACTORS INFLUENCING THE TOLERANCE OF LIGHT AND VISUAL ACUITY*

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INTRODUCTION

The problem of light tolerance has been studied from numerous points of view but most of the studies have not been fruitful so far as producing usable constants are concerned. Van Lear (1940) has touched on some vital related points in his study of the optical properties of reflector signs. It is shown that a very small object, such as a reflector button ⅝ inch in diameter, will be visible for a distance of from 1000-2000 feet. At such distance the wave front from a headlight cannot exceed .05 f. c. with the best luminant now in use on automobiles and is more likely to be of the magnitude of .01 f. c. or less. The return beam has been calculated by Lear (1940) and found not to exceed .0001 foot candle at 100 feet, which would be equivalent of 1/1,000,000th c. p. at a distance of 1,000 feet. Although the glare effect is small at this distance it indicates, in a degree, the enormous sensitivity of the retina. A ⅝ inch button cannot be perceived as such, at this distance but it stands out strikingly as a reflector of such small amounts of light. According to the Snellen standard of a 1-minute angle, it would need be at least 6 inches in diameter or 10 times larger to be discriminated in daylight. Lebensohn (1937) has given interesting data on the amount of light needed for vision while Roper and Scott (1939) have done extensive work on seeing under headlight illumination.

Forbes (1939) has shown that the effectiveness of reflectorized highway signs is greatly reduced by a semi-illuminated background. Acuity as a function of the intensity of the stimulus was early demonstrated by Koenig (1897) and has been more recently reviewed by Hecht (1928) in the formulation of his theory of vision. The many studies of Feree and Rand have added much to the knowledge of this relationship. It must tentatively be assumed that the relationship is relative, rather than absolute, and that any factors which may affect the basic contrast-ratios, tolerated by the eye, will affect it. It has been pointed out that any figure-background contrast-ratio which exceeds 50-1 is more or less unpleasant to the eye. It has also long been held that the retina has a differential index and that the upper part is much more sensitive than the lower part.

THE PROBLEM

The present paper deals with the simple empirical problem of conditions which affect the perception of stimuli under given conditions of opposing light in scotopic vision. Three problems were set for experimental investigation: (a) the effect of intensity of light on visual discrimination, (b) the effect of angle of declination of the

* This study was carried out in the Engineering Experiment Station at Iowa State College.

opposing light, and (c) the differential discrimination of colored objects with and without opposing light.

APPARATUS AND METHOD

A dark booth was uesd for these experiments. Aside from a realistic miniature-roadway extending in front of the subject, the other apparatus employed was a Feree-Rand acuity meter used as described by Lauer, (1942), as a projector and calibrated at 100 volts, anda pair of opposing lights of variable focus and intensity. Also an American Automobile Association visual test chart and a Snellen chart were used as the primary stimuli. Calibrated photronic cells with Viscor filters and a d'Arsonval galvanomter were used for emasurement of light. A MacBeth illuminometer was used as the calibration standard. For further description of apparatus and test objects see Lauer, Merriam and Uhlander (1941).

The subjects were placed in a light-proof hood and adapted for at least 15 minutes to almost total darkness. A series of test letters were then run by successive presentation on a slide through an aperture 3x3 inches. The letters were black on white with a neutral gray background surrounding the aperture. The acuity meter diaphragm was gradually opened until the subject could accurately call the letter. The diaphragm then was closed, another letter inserted and the same procedure followed until the series of stimulus letters was completed.

After a series with no opposing light, a second series was presented with variations in intensity, or angle of the opposing light, according to the experimental procedure being carried out. The intensity variations were made in steps of .25 foot candle, including the following: .25, .50, .75, 1.00, 1.25, 1.50, 1.75, and 2.00 foot candles at the eye, as measured by a Weston photronic cell with Viscor filter. The angle of declination of 3 degrees was maintained during the intensity series. For the angle measurements the opposing light was held constant at 1 foot candle. For the color measurements both the angle of 3 degrees and the oposing light of 1 f. c. were held constant. The magnitudes of all the variable stimuli were rotated in order of presentation to avoid any effects produced by fatigue, ennui, or other factors.

RESULTS

The results will be presented under the respective headings of the variables studied: (a) intensity, (b) angle, and (c) color. They will be designated as Series I, II, and III.

SERIES I

In Series I, thirteen subjects were used, having acuity of 65% or greater. Most of the subjects were near normal. Results are given in Table I.

TABLE I

Relation Between Angle of Opposing Light and Visual Acuity

(12 Subjects)

Subjects Acuity	Dark	Angle of Opposing Light 5°	4°	3°	2°	1°	
Mean candle power required for 8 subjects with 100 per cent vision	0.817	1.976	3.202	3.562	5.409	8.118	
Mean candle power required for 4 subjects with 69 per cent vision	2.939	4.053	5.756	6.503	7.393	9.472	Total Mean Ratio 1.97
Average	1.878	3.014	4.479	5.032	6.401	8.795	
Ratio of Advantage for superior vision	3.59	2.08	1.79	1.83	1.36	1.16	

By the method of least squares the linear relationship for acuity standards, between the limits of 10 and 100 per cent, and light required for accurate seeing or visual discrimination at that level, with opposing light of from 1-2 foot candles, is shown by the equation:

$$y = .0556\,x - .1412, \text{ equation } (1)$$

where x is acuity standard and y is the required light in foot candles for accurate discrimination of the letters used as stimuli. The equation holds between 1 and 2 foot candles of oppising light. It may be used to determine the amount of headlight llumination necessary at a given point along the roadway, with at least a 3° angle of declination, when a given standard of acuity is desired.

The relationship between intensity of illumination on the test object and degree of opposing light for 100 per cent acuity is given by the equation:

$$y = 4.112\,x - 1.112, \text{ equation } (2)$$

when x is the pposing light in foot candles and y is the intensity of illumination required for 100 per cent visual standards. Use this equation to determine the degree of illumination required to offset a known amount of opposing light between zero and one foot candle. The equation holds only for a visual acuity standard of 100 per cent. Other constants must be used for lower level acuity standards and other equations determined since the latter are not linear. In any case constants may be computed for such acuity levels as desired.

SERIES II

Series II was carried out in a similar manner using 12 subjects. The illumination was held constant but the angle varied between

1° and 5°. The angle order was again rotated although the "dark" series was given first since another adaptation period would be necessary if the eyes were subjected to high intensity light. Table II

TABLE II

Comparison of Two Visual Groups with 3° Angle at Different Acuity Levels
Acuity Standard of Letters Used*
Per Cent Letters

Subjects Acuity	10	20	40	60	80	100	120	140	
100 per cent	0.256	0.898	1.195	2.238	2.896	5.096	7.236	8.685	
69 per cent	0.723	1.131	3.627	5.488	8.204	10.212	10.610	12.000	Total Mean
Average	0.489	1.014	2.411	3.863	5.565	7.654	8.923	10.342	Ratio
Ratio of advantage for superior vision	2.82	1.14	3.04	2.45	2.86	2.12	1.45	1.38	2.16

* The 10 per cent letters subtended an angle of 50 minutes, the 20 per cent letters subtended an angle of 25 minutes, the 40 per cent letters subtended an angle of 12½ minutes, etc.

gives the means of the two groups, divided on the basis of acuity.

Comparison by acuity and angle standards shows that a difference of 30 per cent acuity at the levels studied makes a very pronounced and consistent difference at all levels of acuity and at all the angle relations studied. When mean light requirements are above 5 or 6 foot candles the results are less reliable since the luminant used gave a maximum of 10.50 foot candles, as calibrated. Consequently it did not indicate the full significance of the differences at the upper levels as a few were unable to discriminate the stimuli at all with full opposing light.

It is shown that the greatest relative effect of opposing light, in relation to angle, so far as acuity levels are concerned, takes place at the 5° angle while the greatest absolute difference comes at the 3° angle. For subjects with normal vision the effect of 1 foot candle of opposing light at 1 degree of angle increases the amount of light for accurate discrimination by 10 times over that needed for comparable discrimination in darkness, when the total acuity-standard range is considered. For those with 69 per cent vision the relative requirements at 1 degree of angle are but 4 times that for darkness. It must be kept in mind, however, that the 69 per cent group required about 3½ times as much light in darkness for the same visual acuity standard. Over the entire range of values, those with 69 per cent vision required twice as much light as those with 100 per cent vision.

SERIES III

The Series III experiments have to do with two factors, each of which was studied with and without opposing light. Series I and II used as a criterion visual acuity as such. Series III deals only with, (1) the visibility, and (2) color discrimination thresholds for objects of different color and reflection factor. Both were studied with and without opposing lights.

Eighteen subjects, three women and fifteen men, were used in this study. Each was first measured for acuity and placed in the adaptation hood as in the former experiments. Twenty-four dolls, each 1½x3 inches were used as stimuli exposed in a 3x3¼ inch aperture with a flat black background of less than 4 per cent reflection factor. The size described would place them at about an 8 per cent acuity standard and no subject had less than 65 per cent vision. Thus acuity, in the technical sense, was not a factor to be considered in this series. The problem of wave length could only be generally studied from these data and will not be considered here.

The dolls were measured for reflection factor. This was plotted against the amount of light required for first appearance of the image and the reflection factor.

The function obtained is an organic decadence-type curve having the general form: $y = be^{-ax}$, but no constants have been calculated at present writing. Table III shows the comparison of mean values obtained in Series III with certain ratios of the observed values.

TABLE III

Effect of Opposing Light on Visibility and Color Thresholds

Foot candles impinging light required at angle of 3°

Variable	No Opposing light	Opposing light	Ratio
Visibility Threshold	0.032	0.918	28.50ϕ
Color Threshold	2.386	5.774	2.41ϕ
Ratio	74.200	6.240	

SUMMARY AND CONCLUSIONS

An analysis of data from 43 subjects, on the effect of angle of source, intensity of opposing or interfering light and its effect on discrimination of color under conditions of scotopic vision gave the following results. Conclusions are tentatively drawn in full consideration of the limitations of the study.

1. Interference from opposing lights at a 3 degree angle from the line of vision decreases visual acuity gradually until 1 foot candle is reached. Between 1 and 2 foot candles, very little if any decrease takes place. Since headlights, as made today, will not give over one foot candle at the eye-height of the driver, when meeting a car, it seems the intensity could be materially increased without producing hazards of glare.
2. It is possible to estimate with considerable accuracy the amount of illumination necessary for a given acuity standard and a known amount of opposing light. Formulae are given for this purpose.
3. One of the most important factors in the loss of visual efficiency from opposing light is its position in the field of vision. The effect at 1 degree from the line of vision is at least 3

times the effect produced at 5 degrees. Looking down or to the right shoulder when meeting a car should materially reduce glare effects.

4. Thirty per cent loss in visual acuity requires double the light on the test object to equate the efficiency of vision. Persons with acuity below 20/30 should be restricted in speed when driving at night.
5. The visibility threshold for objects of 8 per cent acuity standard and varied reflection factors is increased 28.50 times by opposing lights of one foot candle set at 3°. Depressing the headlight beam when passing will reduce the light at the eye to .20 f.c. thus reducing glare effects to about ¼ that experienced with the high beam.
6. There is further evidence that the reflection factor is much more important than color and that it will account for about ¾ of the increase in light required for threshold discrimination. In other words, it takes about one-fourth as much light to discern light objects as dark objects.
7. The color threshold was found to require about 75 times as much light as the visibility threshold.
8. Inspection of classified data indicates that yellow and light tints of pink and purple have considerably higher color discrimination thresholds. Opposing light seems to nullify noticeable differences in this respect as it greatly increases the threshold.

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