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THE DESIGN OF NUMERALS FOR USE IN COUNTER-TYPE INSTRUMENTS: A REVIEW OF THE LITERATURE

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INTRODUCTION

Workers in the field of visual acuity generally agree upon the existence of four fundamental factors affecting visibility. Cobb and Moss (16) list these as (1) the size of the critical detail to be perceived, (2) the contrast between object and background, (3) the brightness level to which the object is illuminated, and (4) the time the image is allowed to rest on the retina. Ferree and Rand (27, 28) add a fifth to this list, namely, color. These five variables are all interrelated in determining the visibility of any given object. The data presented under the review of each variable should make this clear.

SIZE OF CRITICAL DETAIL

The size of critical detail is normally measured in terms of visual angle. The visual angle is the measure of size in terms of minute of arc at the eye. Ferree and Rand (20) report significant gains in the speed of discrimination as the visual angle, as measured by the Landolt ring, is gradually increased from 1.15 minutes of arc to 3.45 minutes of arc. Figure 1 graphically presents these findings. Another report (24) by the same authors states, in summary, that increasing the size of the visual angle will increase the speed of discrimination at any level of illumination. It was further demonstrated (20,24) that a greater change in speed of discrimination could be brought about by varying the visual angle than by varying the intensity of illumination. This position is also upheld by Cobb (12) when he states that an increase in size of the test-object will increase the speed of discrimination at any brightness level. Further, this speed of discrimination reaches its maximum at a lower brightness level for a large object than for a smaller object. Reporting further on the relation of size to visibility Cobb and Moss (15) report that if the minimum brightness required for the visibility of a test-object 1.5 in size is used as a base, i.e. as 100% illumination, then only 11.5% is required for a test-object 2 mm in height and 1.5% for a 3 mm object. Berger (7) reports the minimum visual angle decreases as the retinal brightness of the object increases.

Averaging the findings of several workers Luckiesh and Moss (42) find that "the size of the smallest object which may be recognized in detail is about one minute visual angle". This figure will, of course, vary as the test-object, brightness, and form vary. For example, black on white appears smaller than it actually is physically while white on black appears larger than it is physically. This phenomenon known as irradiation (38,40) will affect the threshold size of the stimulus.

The generally prevailing concept that, all other factors being equal, the minimum visual angle will remain constant as the distance increases (39) is challenged by Berger (7). He found that when using

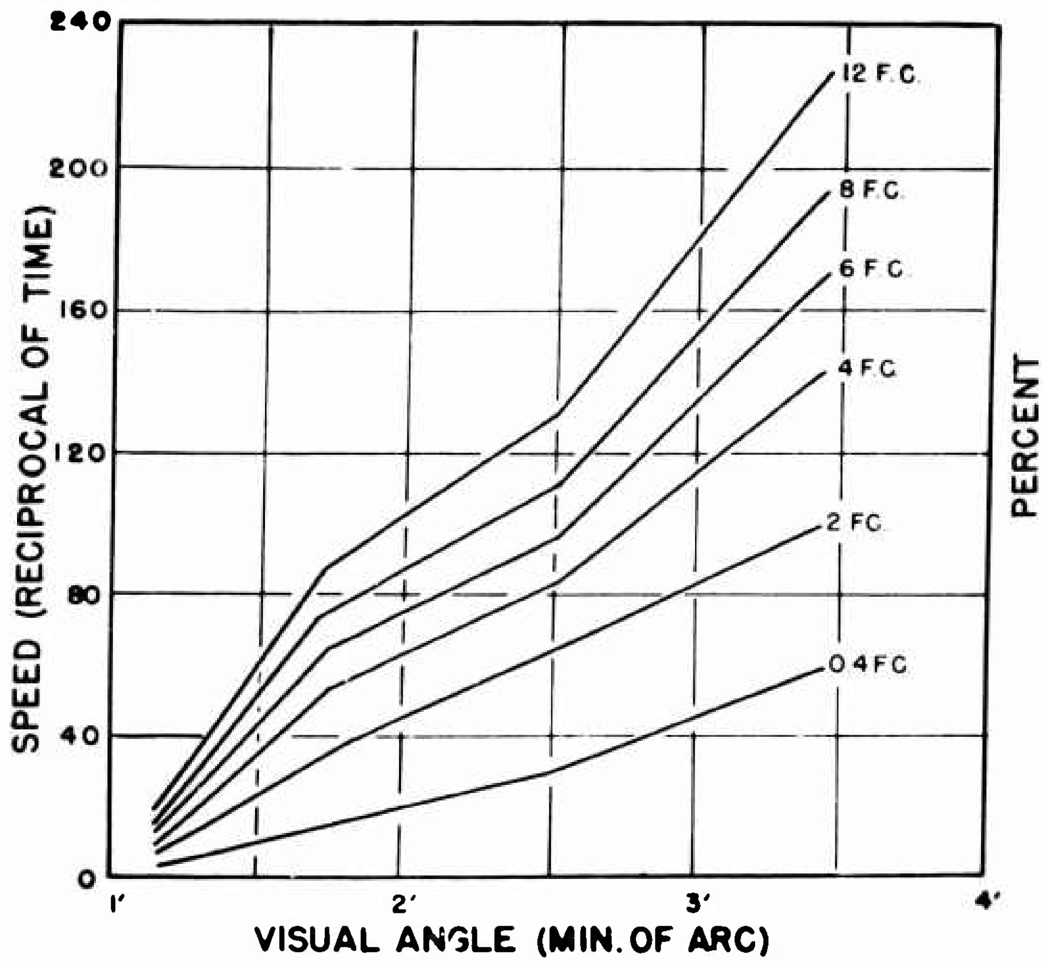

Fig. 1. Relationship between size of visual angle, speed of discrimination, and illumination. Based upon results from 13 observers. (After: Ferree, C. E. and Rand, G. The effect of variation of visual angle, intensity, and composition of light on ocular functions. Trans. Illum. Eng. Soc., 1922, 17, 69-102.)

dots as test-objects the minimum visual angle increased with an increase in distance of observation in all cases when the test-object was viewed under reflected light. When the object was viewed under transmitted light, he found the minimum angle to be constant. No other worker has presented any further support for this finding.

CONTRAST BETWEEN OBJECT AND IMMEDIATE SURROUND

It is definitely agreed that as contrast between the test-object and its background increases, other factors constant, the visibility of the object increases. Cobb and Moss (15) report a typical study in which it was found that a 2 mm test-object required only 11.5% of a base brightness for visibility with a contrast ratio of 100:4, while requiring 112.0% of the base brightness with a contrast ratio of 100:73. The same study indicated that for a 4 mm object 1.5% was required under the first condition and 8.9% under the second. A complete table of data for 1.5 mm, 2mm, 3 mm, and 4.5 mm test-objects (parallel bars) with exposures of

.05, .1 and .2 second for both high and low contrast is presented in Table I.

Concerning this same data it is pointed out by Cobb (13) that the effect of changing from high brightness contrast (100:4) to low contrast (100:73) was approximately equal to reducing the size of the test-object, at a contrast ratio of 100:4 from 3 mm to 2 mm or from 2 mm to 1.5 mm. Ferree and Rand (24) summarize their findings by saying that the greater the difference in the coefficients of reflection for the object and its background the lower the illumination required for equal acuity.

TABLE I

THE RELATIVE BRIGHTNESS OF GROUND OF TEST-OBJECT REQUIRED FOR TEST-OBJECTS OF VARIOUS SIZE AND CONTRAST, EXPOSED FOR VARIOUS LENGTHS OF TIME. THE BRIGHTNESS OF THE 1½ MM. TEST-OBJECT EXPOSED FOR .050 SECOND IS TAKEN AS 100. FOR A SELECTED GROUP OF SUBJECTS THIS VALUE WAS ABOUT 50 ML., FOR A RANDOM GROUP, 100 ML.*

	Per cent brightness required for visibility					
Contrast	High contrast 100:4			Low contrast 100:73		
Time of Exposure	0.05 Sec.	0.1 Sec.	0.2 Sec.	0.05 Sec.	0.1 Sec.	0.2 Sec.
Size of object						
1½ mm.	100.0	25.7	8.1	----	----	----
2 mm.	11.5	4.5	1.7	112.0	26.3	9.3
3 mm.	1.5	0.5	0.3	8.9	2.9	1.4
4½ mm.	----	----	----	2.0	0.7	0.3

*One millilambert is the brightness of a perfectly diffusing surface having a reflection factor of 80 per cent under an illumination of 1.16 foot-candles.

(From Cobb, P. W. and Moss, F. K. Lighting and Contrast. Trans. Illum. Eng. Soc., 1927, 22, 195-204.)

In studying low brightness levels (.0001 to 1.0 millilamberts) Luckiesh and Moss (42) found that acuity increased with contrast increase. Further, this increase was more rapid in the higher levels of the illumination range studies than in the lower. Holding brightness constant at 100 millilamberts the same workers (41) found that as the per cent contrast increased from 1.7% to 5% to 50% the size of the test-object which was just visible decreased from 20 minutes of arc to 2.5 minutes to .9 minutes.

In a somewhat different study Luckiesh and Moss (43) used the blinking rate as an index of fatigue in reading and found that "when the contrast between the object and its immediate background is increased, visibility and ease of seeing are correspondingly increased".

Some experimental data obtained by Wilcox (67) indicates the possibility of an exception to the principle stated above. With the space between two parallel vertical metal bars as the detail to be discriminated he found that the following relationship existed: when the illumination of the test-object was varied and the ground was kept dark, the threshold was very high at low intensities and as the intensity was increased the threshold decreased to a certain minimum and then rose again. The threshold was measured in terms of visual angle. In repeating the experiment with the test-object again illuminated at varied intensities but this time with the ground illumination held constant at 3.4 photron the same general relationship was found between intensity of illumination of the test-object and the threshold of visual angle. Under the conditions of the test-object being dark, or held at a constant brightness less than that of the ground, Wilcox found the general rule presented at the beginning of this section held true, i.e. as the contrast increased the threshold of visibility decreased.

CONTRAST BETWEEN IMMEDIATE TASK AREA AND SURROUNDS

Cobb and Geissler (14) found, using parallel bars as test objects, that illumination outside of the task area greater than that of the task area itself tended to reduce visual acuity. Figure 2 graphically portrays their findings with respect to acuity. Further study by Cobb (10) leads to his conclusion that "surroundings of a brightness equal to or less than that of the test object show no consistently better or worse results than dark surroundings with the identical test object.

A later study by Cobb and Moss (15) gives rise to their statement that "there was no sensible difference in speed of vision between conditions of light and dark surroundings more than 2 or 3 degrees removed from the center of vision". This conclusion was based upon a study of the time required for perception of a simple black dot under conditions of (1) "light" surroundings of brightness equal to that of the dot's background and (2) "dark" surroundings where the illumination was restricted to an area 5.8 by 5.2 degrees in the visual field. Table II presents the summary data for this study.

Additional research (15) with a smaller immediate field and a different task yielded somewhat different results. The task was "the precision setting of a movable pointer into opposition with a fixed

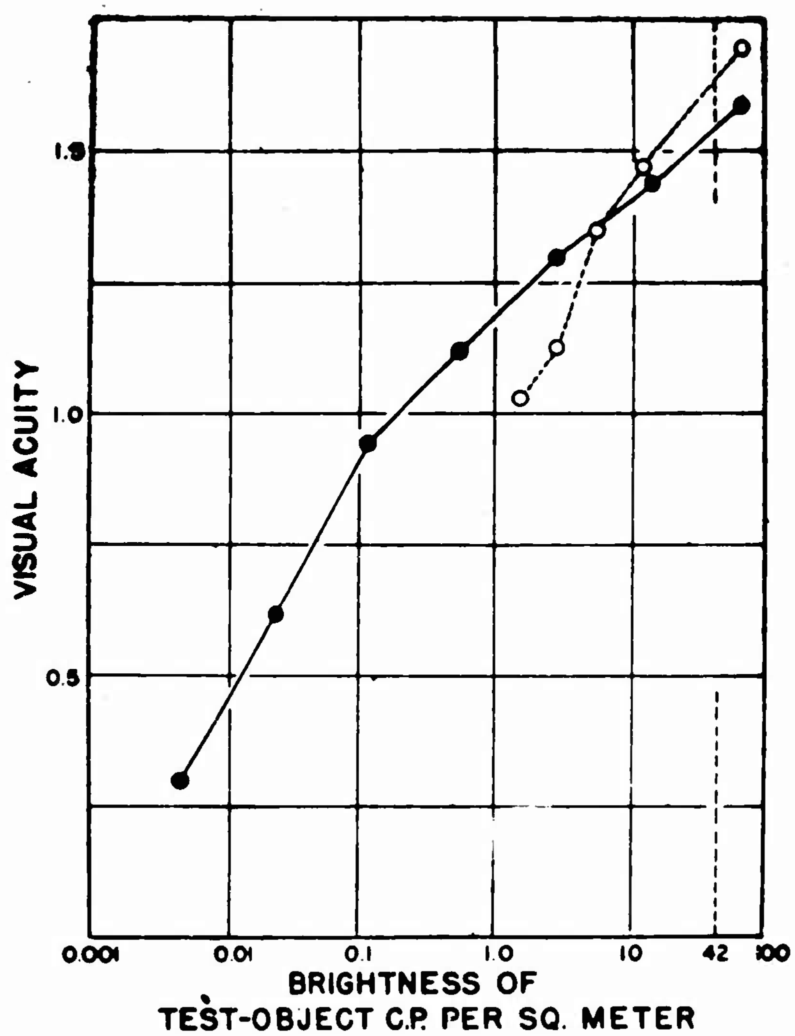

Fig. 2. Mean visual acuity under various conditions.
Dark surroundings ______________
Surroundings 42 candles per square meter------------
(After Cobb, P. W. and Geissler, L. R. The effect on foveal vision of bright surroundings. Psychol. Rev., 1913, 20, 425-447.)

one, both seen in silhouette on a field of brightness specified, subtending 3/4 by 1 degree in the visual field". The measure of accuracy used was the mean deviation expressed in centimeters. Table III presents their findings.

Though the obtained differences are consistently in favor of the "light" surroundings there is no statement made of the reliability of these differences.

Further investigation was performed by Johnson (35) using discrimination reaction as a task. The test field was 3 degrees in size and following surround--test field illumination ratios were employed,

TABLE II

THE TIME OF EXPOSURE NECESSARY FOR VISION OF A SIMPLE BLACK DOT, IN EXTENDED "LIGHT" SURROUNDINGS OF BRIGHTNESS EQUAL TO THAT OF ITS BACKGROUND AND "DARK," WITH BRIGHT SURROUNDINGS RESTRICTED TO 5.8 X 5.2° IN THE VISUAL FIELD. THE SURROUNDINGS OUTSIDE OF THIS LIMITED AREA ARE INDIFFERENT FOR VISION.

Brightness in Ml.	Time in 0.001 seconds		
	Light	Dark	Mean
107.0	6.79	6.82	6.80
63.1	7.08	7.38	7.23
33.0	8.71	8.61	8.66
16.2	9.95	10.05	10.00
7.8	13.40	13.20	13.30

(From Cobb, P. W. and Moss, F. K. Lighting and Contrast. Trans. Illum. Eng. Soc., 1927, 22, 195-204.)

TABLE III

THE PRECISION OF SETTING A MOVABLE POINTER INTO OPPOSITION WITH A FIXED ONE, BOTH SEEN IN SILHOUETTE ON A FIELD OF BRIGHTNESS SPECIFIED, SUBTENDING 3/4 X 1° IN THE VISUAL FIELD. THE VALUES STATED ARE THE MEAN DEVIATIONS OF INDIVIDUAL SETTINGS FROM THEIR MEAN IN EACH CASE, EXPRESSED IN CENTIMETERS. DISTANCE OF OBJECT, 3 METERS. THE RESULTS SHOW THE VISUAL DISADVANTAGE IN WORKING UPON A SMALL BRIGHT FIELD IN DARK SURROUNDINGS.

Brightness	1.00 ml.	4.18 ml.	20 ml.	91.50 ml.
Light surroundings	.0649	.0619	.0584	.0552
Dark surroundings	.0745	.0690	.0618	.0625

(From Cobb, P. W. and Moss, F. K. Lighting and Contrast. Trans. Illum. Eng. Soc., 1927, 22, 195-204.)

(1) 0.015, (2) 0.34, (3) 1.14, (4) 3.87, (5) 6.43, and (6) 9.45. Three measures of performance were obtained in the experiment, (1) average discrimination reaction time, (2) variability of reaction time and (3) relative number of errors. It was found that average reaction time

was shortest under illumination condition 3 (approximately equal test field and surround) than under any other condition which exceeds that ratio. The increase in reaction time was greater the farther the ratio was exceeded. It was found that when the surround was less bright than the test field the effect on reaction time was inconsistent. In general, however, the trend appeared to be toward increased reaction time. Using an integrated measure of all three criteria listed above, Fig. 3 presents a graphic representation of the trend line presented by Johnson.

BRIGHTNESS LEVEL

It can be stated that visual acuity, speed of discrimination and ability to sustain clear vision all increase with an increase in brightness level. Using the broken circle as a test-object Ferree and Rand (19) found the speed of discrimination gradually increased with increasing brightness from .4 to 12 foot-candles. The specific findings are presented in Table IV. These data are based upon averages from a study conducted with seven observers. It was further revealed that both speed of discrimination and acuity increase with increased brightness from .001 to 20 foot-candles. A further analysis of the same data (21) revealed that as the illumination was increased, (1) from .001 to 1.0 f.c. the minimum visual angle changed from 7.143 minutes to 1.213, a gain of 589% in acuity, (2) from .1 to 1.0 f.c. the visual angle was reduced from 1.213 minutes to .741 minutes, a gain of 63.7% in acuity, (3) from 1 to 5 f.c. reduced the visual angle from .741 to .516 minutes, a gain of 43.6% in acuity, and (4) from 5 to 20 f.c. reduced the visual

TABLE IV

SPEED OF DISCRIMINATION VS. ILLUMINATION*

Intensity (f.c.)	Speed (reciprocal of time)
0.4	2.285
2.0	4.985
4.0	6.369
6.0	8.403
8.0	10.040
12.0	15.152

*Based upon 7 observers (averages)

(From Ferree, C. E. and Rand, G. The effect of variation in intensity of illumination on functions of importance to the working eye. Trans. Illum. Eng. Soc., 1920, 15, 769-801.)

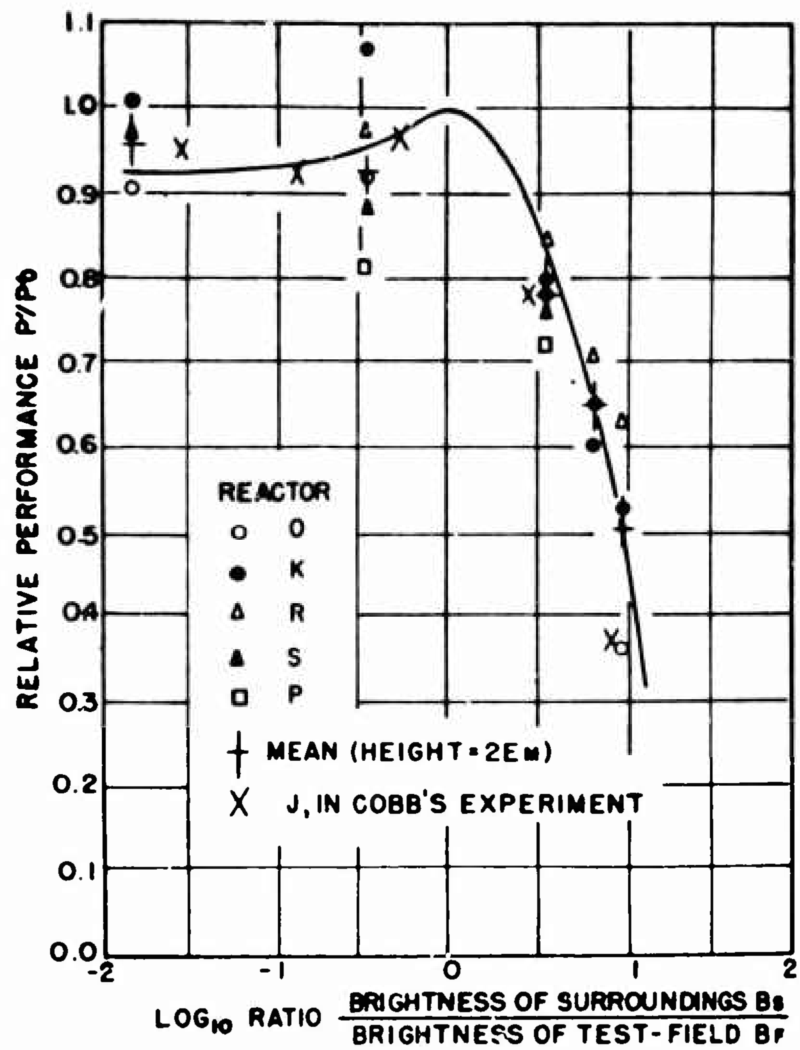

Fig. 3. Relationship between reaction time and brightness contrast of test field and surroundings. (After Johnson, H. M. Speed, accuracy, and constancy of response to visual stimuli as related to the distribution of brightnesses over the visual field. J. exp. Psychol., 1924, 7, 1-44.)

angle .516 to .477 minutes or increased acuity by 8.2%. These data are to be found in Table V. Further evidence of this relationship between illumination and speed of discrimination is revealed by the data to be found in Fig. 4. These data are based upon averages from an experiment conducted with the Landolt ring as test-object, on 13 subjects by Ferree and Rand (20).

Holding the visual angle constant at 1.63 minutes Luckiesh and Moss (41) found that a brightness of 1 millilambert required a contrast of 40.5% for seeing, a brightness of 20 millilamberts required only a contrast of 14.1% and finally 100 millilamberts required 8.13% contrast. The same authors (43) had 11 subjects read for one hour under three

TABLE V

ACUITY VS. ILLUMINATION*

Foot Candles	Acuity	Min Vis Angle	% Increase In Acuity
0.001	0.140	7.143	
0.005	0.2075		
0.010	0.2655		
0.015	.381		
0.02	.483		
0.05	.615		
0.10	.8245	1.213	589%
0.20	1.028		
0.40	1.158		
1.00	1.350	0.741	63.7%
2.00	1.611		
3.00	1.743		
5.00	1.9385	0.516	43.6%
10.00	1.973		
20.00	2.097	0.477	8.2%

*Based upon studies with 4 observers

(From Ferree, C. E. and Rand, G. The effect of variation in intensity of illumination on functions of importance to the working eye. Trans. Illum. Eng. Soc., 1920, 15, 769-801.)

levels of illumination, 1, 10, and 100 foot-candles. Using the blinking rate during the last five minutes as an index of fatigue it was found that with the increasing illumination the blink rate dropped from 60 to 46 to 39. These differences are statistically reliable. Richtmeyer and Howes (55) used speed of reading printed material as a criterion and found the rate increased with each of the six increasing intensities from .1 to 1.5 foot-candles. A plot of these data will be found in Fig. 5. Using parallel black bars as test-objects Luckiesh and Moss (42) found the time for critical vision decreased from .125 to .035 seconds as the brightness increased from 1 to 100 millilamberts.

Ferree and Rand (24,26) note that the large effects of increases of intensity of the speed of discrimination occur in the lower part of the scale of intensities. Luckiesh (38) using a black test-object on white, states that visual acuity increases rapidly with increase in intensity up to approximately 5 foot-candles. Tinker (59) reporting on a study by Lythgoe states that "progressing from low to high intensities, there is a rapid rise in visual acuity up to 5 f.c. With further increase in intensity levels the corresponding rise on acuity becomes slower and slower and almost reaches a maximum at about 20 f.c.

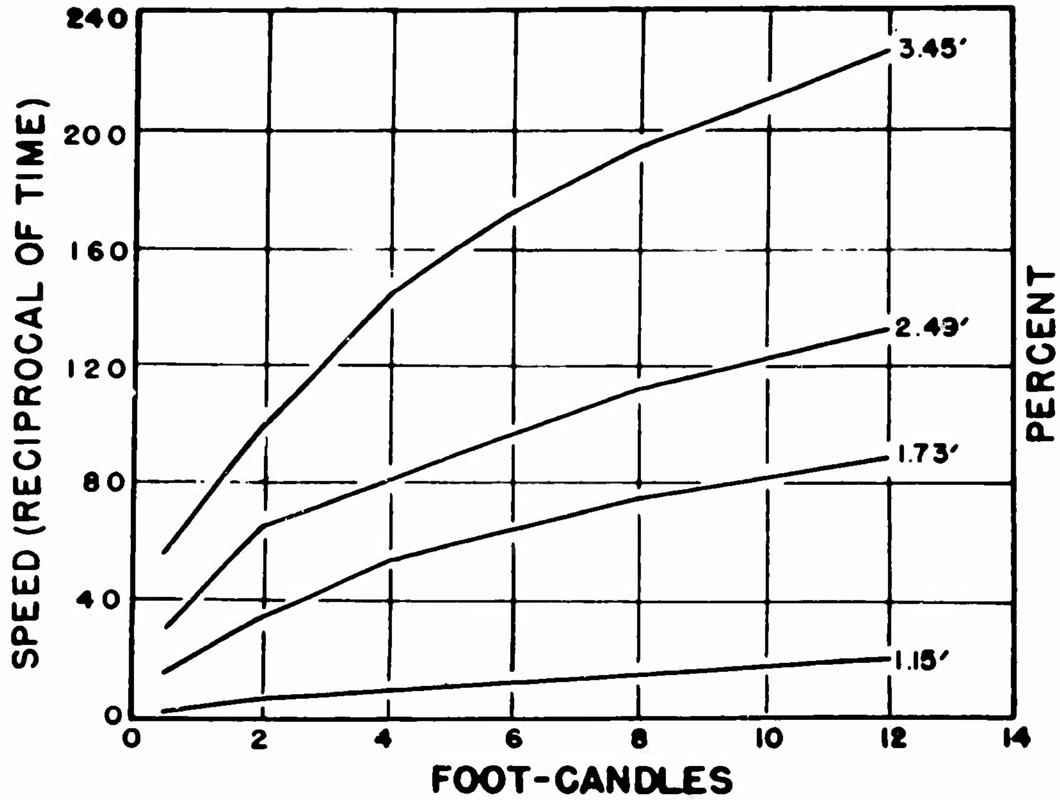

Fig. 4. Relationship of speed of discrimination and foot candles based on 13 observers. (After Ferree, C. E. and Rand, G. The effect of variation of visual angle, intensity, and composition of light on important ocular functions. Trans. Illum. Eng. Soc., 1922, 17, 69-102.)

In fact, improvement from about 15 f.c. to higher levels is scarcely noticable". Troland (61) in reviewing all available estimates places the point at which increased brightness no longer yields appreciable gain on acuity for black objects.

The relationship between illumination and acuity is not a simple arithmetic one. Luckiesh and Moss (48) point out that illumination must be approximately doubled to produce "equal and significant" improvements in seeing. Cobb and Geissler's (14) data indicate that acuity is approximately proportional to the logarithm of the intensity between 0.02 and 21.0 millilamberts. At a later date Cobb's (10) data indicates the span of logarithmic relationship to hold between .06 and 26.0 millilamberts. Johnson (35) finds the logarithmic relation to fall down at the extremes of brightness, both high and low. On the high end the relationship begins to fail at 40 millilamberts and increases in

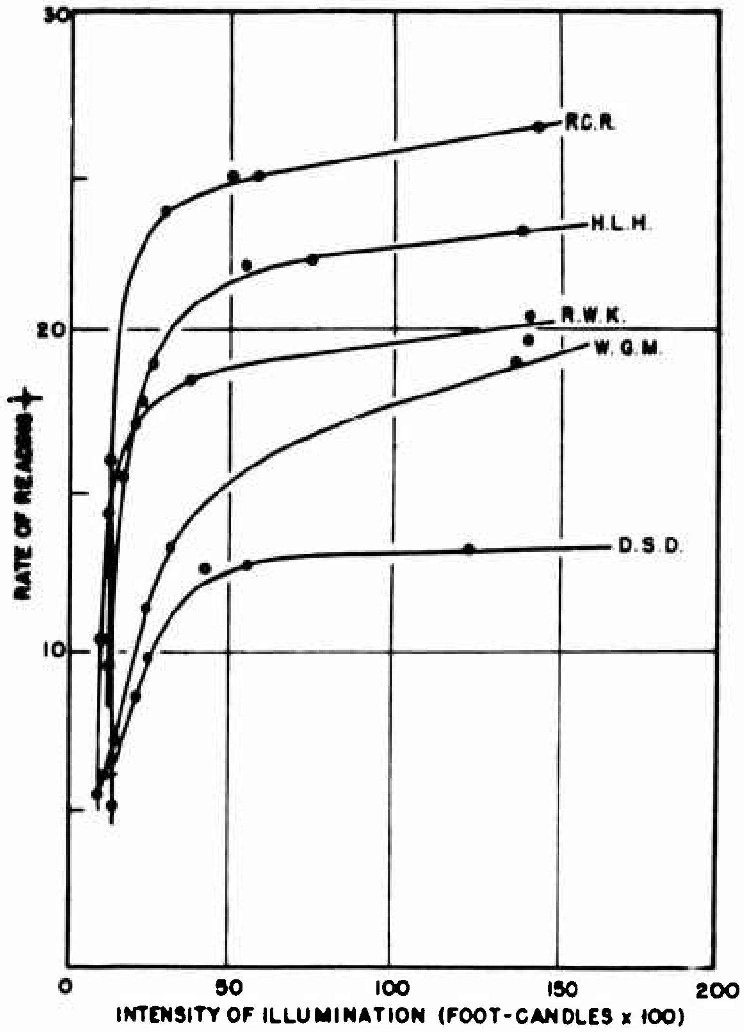

Fig. 5. Relationship between speed of reading and illumination for 5 subjects. (After Richtmyer, F. K. and Howes, H. L. A method of studying the behavior of the eye under different conditions of illumination. Trans. Illum. Eng. Soc., 1916, 11, 100-113.)

brightness over 150 millilamberts result in impaired acuity.

A caution is expressed, by Tinker (60) to all workers in the area of illumination. Namely, it is imperative to make certain that the subjects be adapted to the level of illumination being employed since an appreciable lag occurs between change in intensity and readjustment of retinal sensitivity.

TIME

For the most part time has been used as a criterion by which the effects of other variables are measured. However, the visibility of an object is related to the time it is exposed. A careful analysis of examples of the variation in the factors of contrast, size, and illumination when the results are expressed in terms of speed of discrimination will reveal that as the time is increased acuity also increases. For example, Cobb and Moss (15) found that, when holding contrast and visual angle constant, only 25.7% as high an intensity of illumination was required with an exposure of .1 second as compared to .05 second, and only 8.1% as great intensity was required at an exposure of .2 second as at .05 second. Luckiesh and Moss (41) held visual angle (2.41 minutes) and brightness (100 millilamberts) constant, under these conditions and exposure of .075 second required a contrast of 5.35%, a .17 second exposure only 4.56% contrast and a .30 second exposure only 4.08% contrast.

In connection with this discussion of the factor of time, it should be noted that both Fig. 1 and Fig. 2 may be easily interpreted in terms of time as in terms of the variables they were introduced to illustrate.

COLOR

Tinker (59) states that "color of light as such has little effect upon efficiency and comfort of vision". He goes on to say that sunlight (white light) and yellow light are slightly superior to other colors. No experimental data is presented in support of these conclusions. Luckiesh and Moss (42) claim that a black object on white, red, and green give substantially the same acuity while black on blue is only about one half as efficient.

Ferree and Rand (22,23,26,27,28) made a series of intensive studies of the effect of color relations on visibility. The first of these studies was performed using a black broken circle on a white surface illuminated by seven spectral colors--red, orange, yellow, yellow-green, green, blue-green, and blue. At the higher intensity the order was the same except that blue and blue-green were not producible. Using speed of discrimination as a criterion the same ranking was found. Figure 6 presents these data for the relationship between "speed of discrimination" and color of light for two levels of illumination. As measured by power to sustain clear seeing (criterion is the ratio of the time the break in the circle is clear to the time it is blurred as measured over a three-minute period) the order was the same except that the positions of red and green were interchanged. In the second study saturation and brightness of all colors were held constant and the same criterion were used, resulting in the same ranking of the colors. The range of variation of acuity from the best to the poorest color was reduced under the second conditions.

The black test-object had a higher visibility on white than on any of the colors studied above. The relationship between black and white were also established. The results of the various studies (22,23,26) are summarized below: (1) the effect of increase of light intensity on speed of discrimination are essentially the same for both black on white

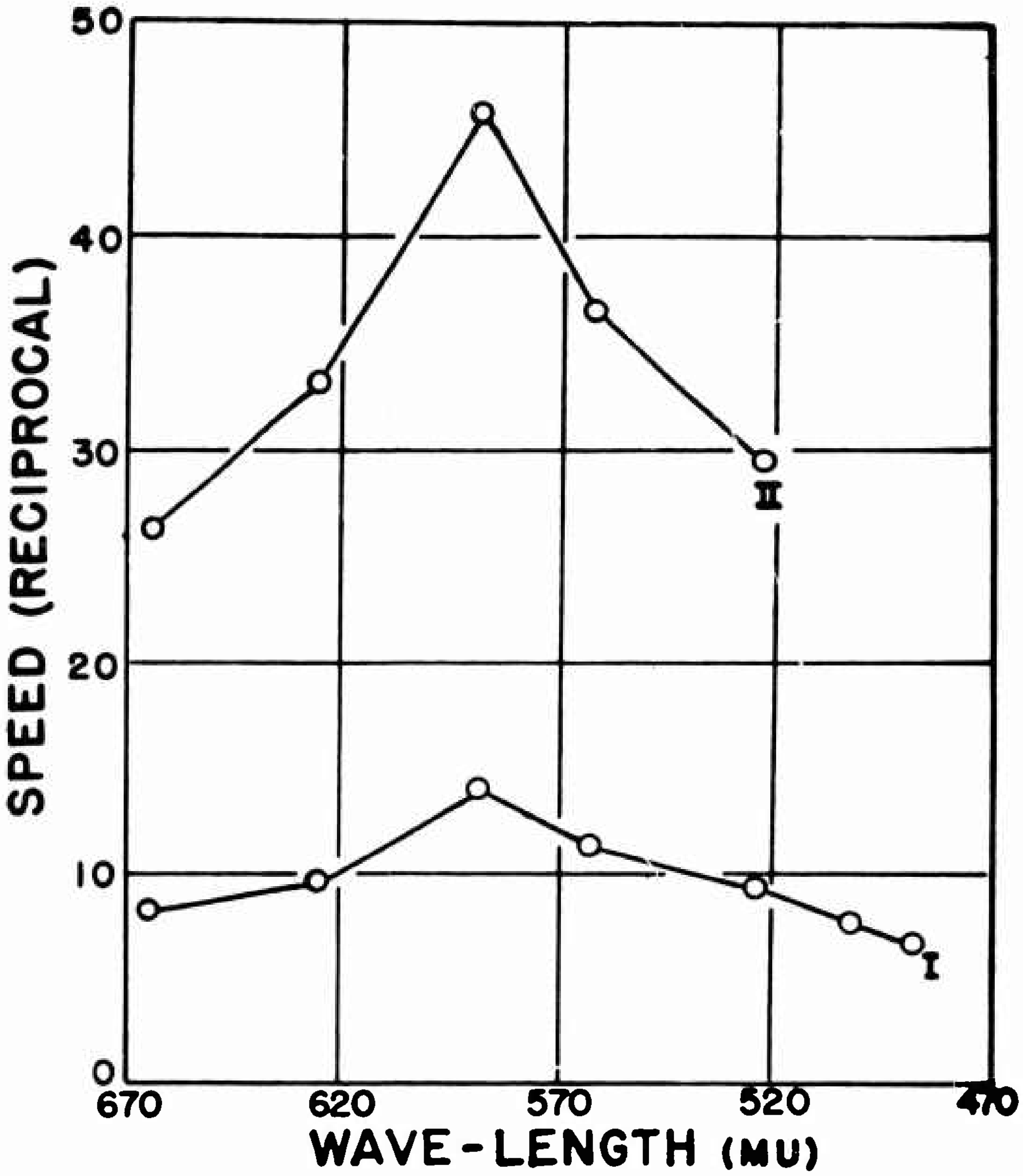

Fig. 6. Speed of discrimination vs. color.
Equal saturation of colors.
I = .075 fc. II = .3116 fc.

(After Ferree, C. E. and Rand, G. Visibility of objects affected by color and composition of light. Part II. With lights equalized in both brightness and saturation. Person. J., 1931, 10, 108-124.)

and white on black, i.e., the greatest increase occurs in the lower portion of the intensity scale, the speed is greater for large differences in contrast, (2) for any given size of detail the sensations from a white letter on black (detail to be discriminated black) must be higher above the threshold to be discriminated than a black letter on white (detail to be discriminated white). This latter relationship also holds when the speed of discrimination is used as the criterion. Figure 7

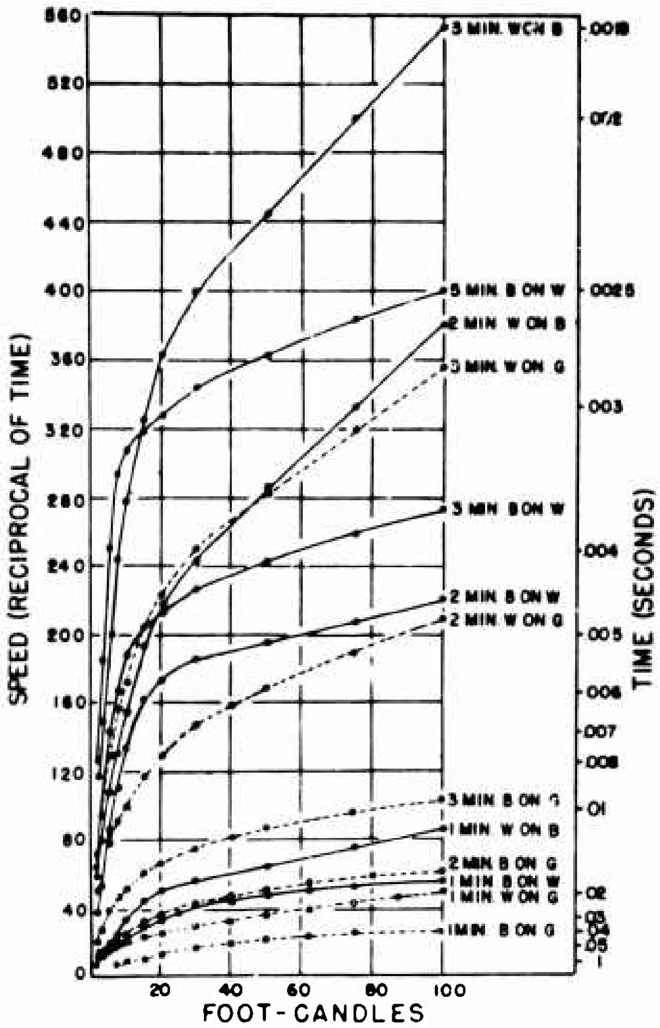

Fig. 7. Curves showing comparison of the effect of increase of intensity of light on speed of vision for 1, 2, and 3 minutes white test-objects (Landolt ring) on black; and 1, 2, and 3 minutes black test-objects on white background; 1, 2, and 3 minutes white test-objects on gray background; and 1, 2, and 3 minutes black test-object on gray background. (After Cobb, P. W. and Moss, F. K. Four fundamental factors in vision. Trans. Illum. Eng. Soc., 1928, 23, 496-546.)

presents the results of an investigation by Cobb and Moss (16).

This study supports the above findings with one area of exception as they state in their findings (16): "In work done on speed of discrimination a black test-object on a white field and a white test-object on black, both in the present study and in an unpublished investigation made in 1924, we have found that for small sizes of objects (1 min. visual angle or less) and low intensities, speed of discrimination is higher for black on white; but for larger sizes of objects and high illumination it is higher for white on black than for black on white....." In the unpublished investigation results were obtained for 5 observers for 1 minute, test-objects and intensities ranging from 0.4 to 12 foot-candles. For all observers the point of transition occurred between 2 and 8 foot-candles.

Results conflicting with those reviewed above were obtained by Berger (8,9) in a study with actual numbers. These data will be presented in a separate section of this review.

INTERRELATIONS BETWEEN VARIABLES

It is most important to realize that the threshold of acuity is dependent upon conditions set up by the various variable factors. For example, the larger the visual angle, the greater the contrast between the object and its background, and the longer the time for observation the less the need for high illumination. Many other similar relations can, of course, be suggested. Cobb and Moss (16) carried out the determination of the specific relationships between the first four variables (size, contrast, brightness, and time) for one test-object and present their findings in a three-dimensional plot. This plot is reproduced in Fig. 8.

SPECIFIC NUMERAL LEGIBILITY

While considerable work has been done in investigating the legibility of letters, relatively little has been done in attempting to determine the characteristics which make one numeral more or less easily legible than another. Tinker (58) found that with 8-point type, the rank order of legibility (based upon errors) of numerals, as extracted from letters and miscellaneous signs as well as numerals, was 7960382541 for lower case and 9734218650 for upper case. Those numerals which are underlined were tied. This study does not throw any light on the relative legibility of numerals when compared only with each other, as would be the case in counter type dials.

The only really pertinent information in this area comes from studies by Dunlap (17) and Berger (8,9). Both of these workers dealt with numerals to be used on license plates. Dunlap analyzed a large number of license plates to determine basic factors in legibility. His major conclusions were that (1) dark numerals on a light background are most legible, (2) wider spacing of numerals increases legibility, and (3) those plates in which the numerals covered less than 25% of the plate area were most legible.

Berger's work was done on numerals covering a standard area of 42 by 80 mm. His first study (8) was concerned with finding the optimum stroke width for these numerals under daylight conditions. The study was conducted only on the numerals 8, 5, and 2 which he selected because "... they differ most but are at the same time most harmonic".

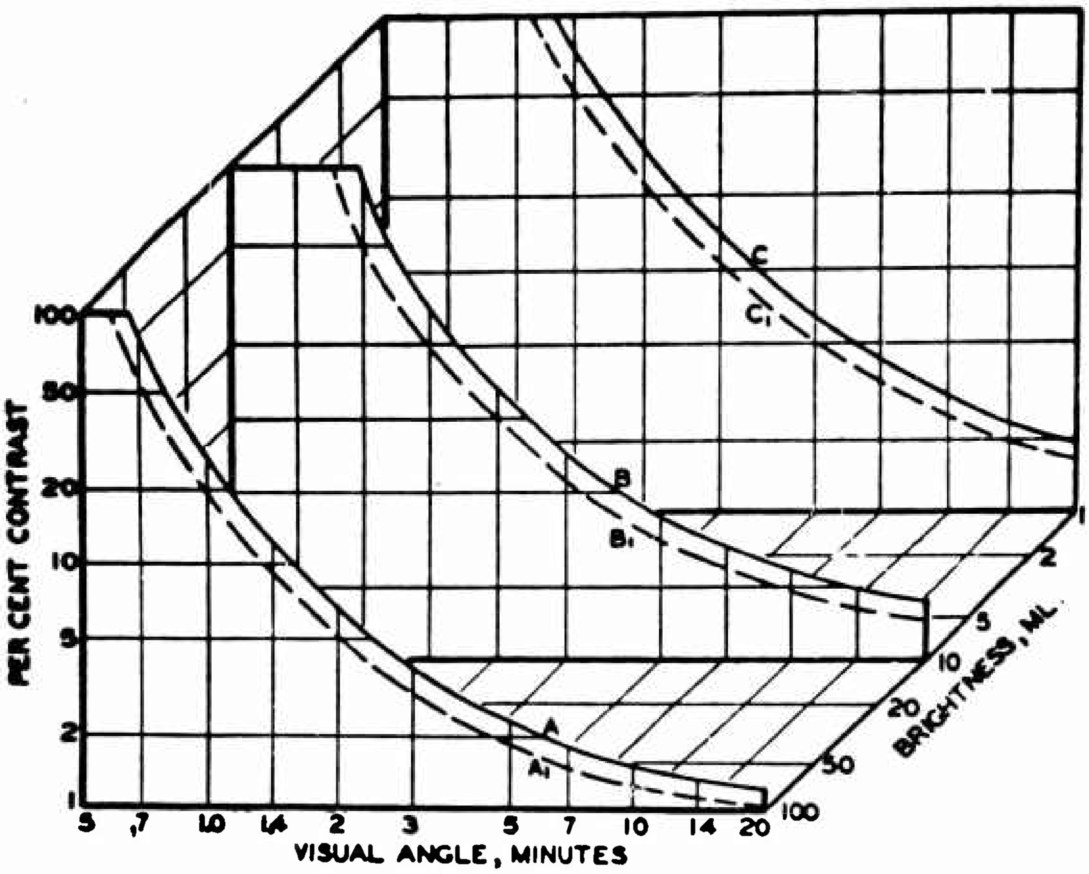

Fig. 8. The relation between size, contrast, and brightness of an object at the limit of visibility; the curves A, B, and C defining a surface expressing the relation of these factors for an exposure time of 0.075 sec. A, B, C, give a similar reaction for an exposure time of 0.300 sec. (From Cobb, P. W. and Moss, F. K. Four fundamental factors in vision. Trans. Illum. Eng. Soc., 1928, 23, 496-506.)

The average threshold distance for two subjects plotted against width of stroke is presented in Fig. 9.

These findings indicate that for the numerals studied, 6 mm is the optimal stroke width for white numerals on a black background, 10 mm is the optimal stroke width for black numerals on a white background. It further is presented that white numerals with optimal stroke width (6 mm) are recognized 8.8% better than black numerals with optimal stroke width (10 mm). A second study (9) was concerned with numerals for license plates under night conditions. Here he found that, "The very slender numerals with a width of stroke of 1 to 2 mm, illuminated from behind

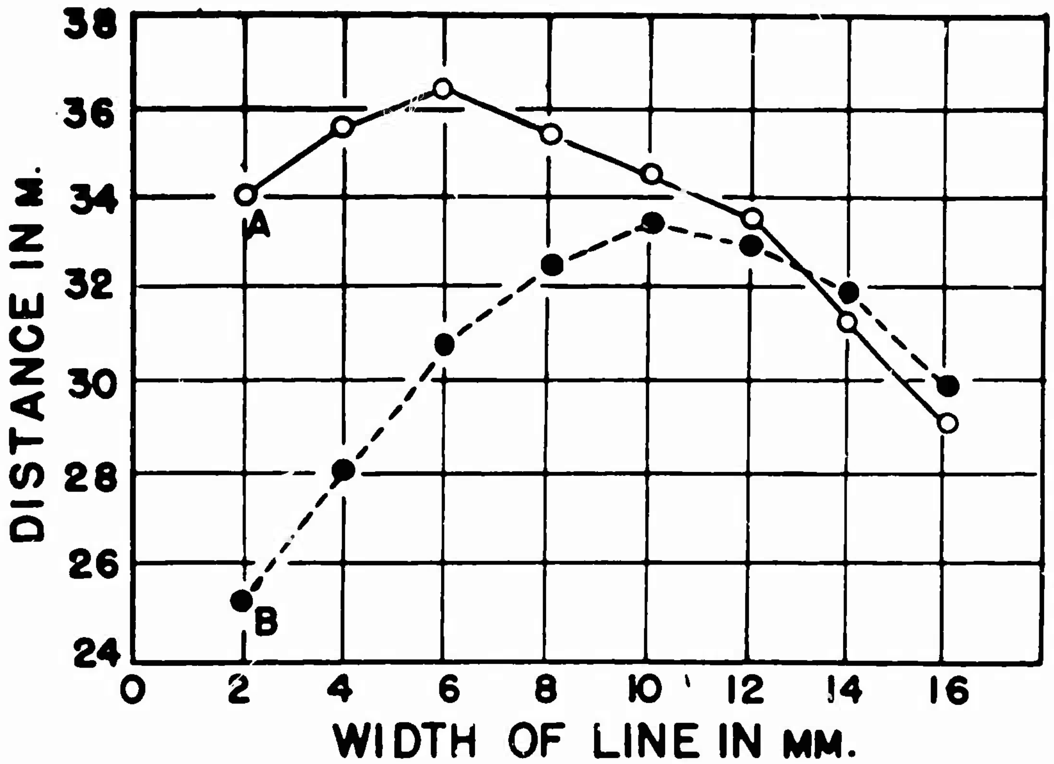

Fig. 9. Influence of stroke width between 2 and 16 mm upon the recognition of 3 numerals (8, 5, and 2) on the constant area: 42 mm x 80 mm 2 observers. Curve A = white numerals on a black background, Curve B = black numerals on a white background. (After Berger, C. I. Stroke width, form and horizontal spacing of numerals as determinants of the threshold of recognition. J. appl. Psychol., 1944, 28, 208-231.)

(luminous), are on the average (5 subjects used) 10 per cent to 18 per cent more recognizable.... than the white numerals of optimal stroke width with reflected, optimal illumination". The luminous numerals had 10 watt lamps as their light source, the numerals for use with reflected light were illuminated by 10 and 15 watt lamps. It will be noted that what is being compared are not equal illuminations but rather maximum practicable illuminations. The results of the study are presented graphically in Fig. 10.

In this report Berger draws several conclusions concerning Dunlap's work in the light of his own findings: (1) as a generalization the statement that a light background with dark numerals gives best results is false, (2) it is true, up to a certain maximum, that numerals spaced further apart give highest legibility, and (3) the statement that numerals with slender stroke are more efficient is not a reasonable generalization as there is an optimal thickness for both black and white numerals.

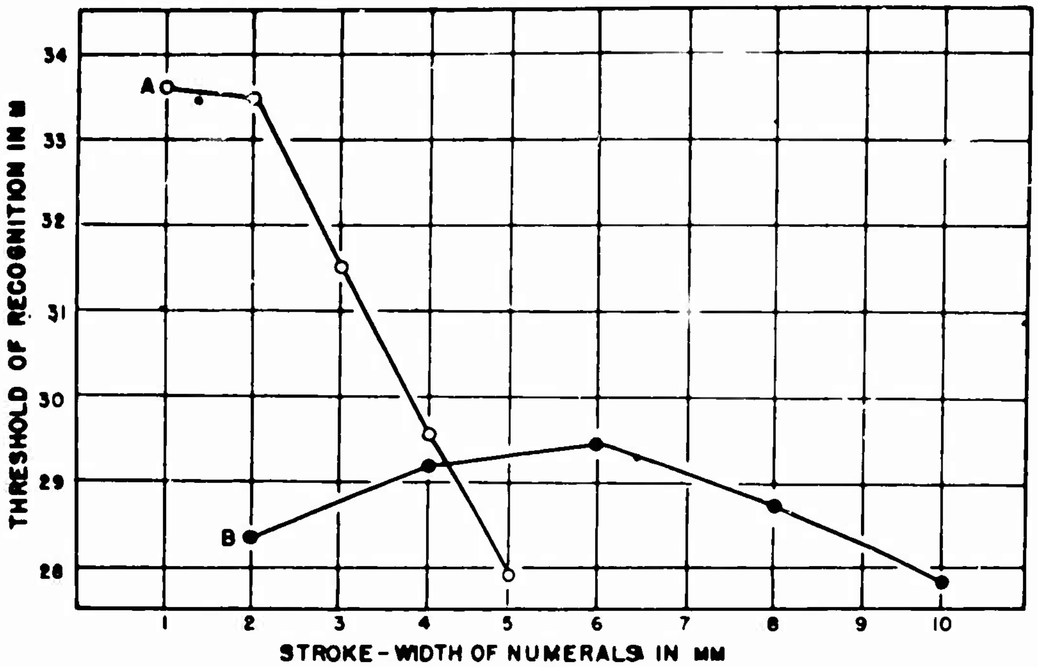

Fig. 10. Dependency of the threshold of recognition upon stroke width of numerals during night conditions (partly dark-adapted). Curve A = luminous curves, Curve B = white numerals with reflected light. (After Berger, C. II. Stroke width, form and horizontal spacing of numerals as determinants of the threshold of recognition. J. appl. Psychol., 1944, 28, 336-346.)

Berger further (8) went on to develop and patent a set of digits (1 through 0) in which all digits have the same threshold of legibility.

CONCLUSION

The works reviewed in the preceding sections appear to provide adequate information concerning the characteristics of the variables studied. It is felt that the restudying of these variables using numerals as test-objects will not add greatly to the facts already available. Rather, it is felt that the preceding summary of the findings of various experimenters in the field of visibility yields considerable data that may be applied directly to the design of numerals for counter-type dials. These may be summarized as follows:

1. The size of the critical detail in the numerals should be as large as is possible within the necessary practical limitations of overall numeral size. Within these limitations, it may be said that the larger the numeral of any given type, the greater will be its

visibility; the larger it is, the more rapidly it can be identified, the larger it is, the smaller the contrast ratio required to be seen, the larger it is, the lower the brightness level required to be seen.

2. The contrast between the numeral and its immediate background should be as great as it is possible to provide. By increasing this contrast ratio for any given numeral type, equal visibility may be maintained when the size is reduced, or the brightness level is reduced, or the time for apprehension is reduced.

3. The brightness contrast between the dial area and the surround should preferably yield a ratio of one. If this is not possible, a reduction of surround brightness below the level of the dial area reduces legibility only slightly. A situation which yields surround brightness greater than dial areas is to be strenuously avoided as this condition greatly reduces acuity.

4. The brightness level of the numeral and its background should be as high as is possible in the situation obtaining. Increasing the brightness level increases the speed and accuracy of apprehension and with the same type numeral a given visibility level may be maintained by increasing the brightness level while decreases in contrast are made or decreases in size are made, or while time for apprehension is decreased.

5. For greatest visibility, other factors held equal, numerals should be either black or white on opposite background. In order of decreasing visibility, in all cases inferior to black on white or white on black, are black on yellow, yellow-green, orange, green, red, blue-green, and blue. The question of the relative merits of black on white and white on black has not been conclusively answered as yet.

In brief then, to provide a counter dial of the greatest possible visibility, each of the above factors should be applied to the greatest extent compatible with other requirements of the situation.

Two other variables exist in the use of numerals, in addition to those presented above, which have not been adequately investigated. These are style of numeral and width of stroke used in the numeral. Little experimental data is available in which these have been analyzed. Therefore, our problem in the study of the design of numerals for use in counter-type instruments is conceived to be the study of these two factors while holding the already investigated variables constant.

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ABSTRACT: Workers in the field of visual acuity generally agree upon the existence of four fundamental factors affecting visibility. These are the size of the critical detail to be perceived, the contrast between the object and background, the brightness level to which the object is illuminated, and the time the image is allowed to rest on the retina. In addition, color may be added to these. These five variables are all interrelated in determining the visibility of any given object. As an example, the larger the visual angle, the greater the contrast between the object and its background; and the longer the time for observation, the less the need for high illumination. Many other similar relations can, of course, be suggested. To provide a counter dial of the greatest possible visibility, the factors should be applied to the greatest extent compatible with other requirements of the situation. Two other variables exist in the use of numerals, these being style of numeral and width of stroke used in the numerals.

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