A New Scale of Relative Footcandles for the Luckiesh-Moss Visibility Meter

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VARIOUS relationships may be obtained to correlate the fundamental factors of size, brightness, brightness - contrast and time which combine to determine the degree of visibility of any object or visual task. These relationships may be used to establish a scale of footcandle-levels for various tasks which will provide a given degree of supra-threshold visibility. However, the direct application of these correlations requires a detailed analysis of each visual task to determine, for example, the critical size that must be discriminated and the contrast between the object and its immediate background. This is difficult and often impossible to accomplish. Therefore, it is highly desirable to develop a means by which any visual task, regardless of its complexity, may be evaluated and its degree of supra-threshold visibility with a specific illumination may be appraised. Furthermore, such a method should make it possible to determine the footcandle-level necessary to raise the visibility of the task to a desired supra-threshold value. A device which permits one to achieve these objectives is the Luckiesh-Moss Visibility Meter.[1]

The relative visibility scale of the meter is calibrated in terms of the sizes of a series of standard parallel-bar test-objects illuminated with 10 footcandles and viewed by an observer with average normal vision. In effect it is a transfer medium by which different visual tasks can be rated in terms of the visibility-levels of the standard series of objects. Units of measurement, of necessity, are defined by arbitrary standards that are relatively simple and readily reproduced. This scale of relative visibility has been applied effectively in the study of the visibility-levels of many diversified tasks.

The present scale of relative footcandles of the meter was designed to enable the user to determine the footcandles required to raise a task to any desirable and attainable visibility-level. The scale has proved somewhat difficult to apply and has been superseded by a family of curves relating visibility and footcandles.[2] While this was a practical step forward in making the visibility meter a more useful instrument, it still left something to be desired. A direct-reading scale that is based upon footcandle values would be more practicable in lighting practice. Fry[3] has prepared an analysis of the Luckiesh-Moss Visibility Meter and has demonstrated how such a scale can be developed from the characteristics of the photographic gradients. The present paper presents the development of a scale of relative footcandles that is based upon the calibration data of the visibility meter and which can be used with simple calculations without requiring reference to charts and tables.

The new scale of relative footcandles is based upon the premise that the ratio of the footcandles for a specific visibility-level to the footcandles for threshold visibility will always be the same regardless of the task. The *actual* footcandle values for the threshold and the specific supra-threshold visibility-level are different for different tasks, but the footcandle-ratios are constant. In other words, each visibility-level can be specified by a corresponding footcandle-ratio or relative footcandle value.

The development of the new scale is illustrated by Fig. 1. The curve represents the relationship between visibility-level and footcandle-level for well-printed 8-point type when viewed by observers possessing average normal vision. The footcandle-level required by these observers to be able to barely read the specific 8-point type (printed with black ink on white paper) when viewing it directly without the visibility meter is 0.01 footcandle. In other words, 0.01 footcandle is the absolute threshold footcandle-level for this particular visual task. The inner left-hand scale of Fig. 1 indicates the actual footcandle-levels required for the various visibility-levels. The relative footcandles with respect to the threshold footcandle-level are indicated by the outer left-hand scale on which the threshold value has been given a value of unity. Thus, any supra-threshold value may be expressed as being a specific multiple of the threshold footcandle-level. For example, the footcandle-level necessary for a visibility-level of 3 is 5.9 which corresponds to a relative value of 590. In other words, a supra-threshold visibility-level of 3 requires an illumination that is 590 times the threshold illumination.

An alternate method of expressing supra-threshold

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footcandle-levels is represented by the right-hand ordinate of Fig. 1. This scale represents equal logarithmic steps above the threshold footcandle-level, each unit corresponding to one log-cycle of illumination. Thus 5.9 footcandles is equivalent to 2.77 log-units above the threshold footcandle-level. This may be stated as $10^{2.77}$ or 590 times the threshold footcandle-level.

Relative footcandles and log-units above the threshold illumination for various visibility-levels are tabulated in Table I.

The significance of Fig. 1 and Table I and their application to objects of other sizes is illustrated by the data of Table II. These data have been obtained from the relationships between footcandle-level and visibility-level for a series of black parallel-bar test-

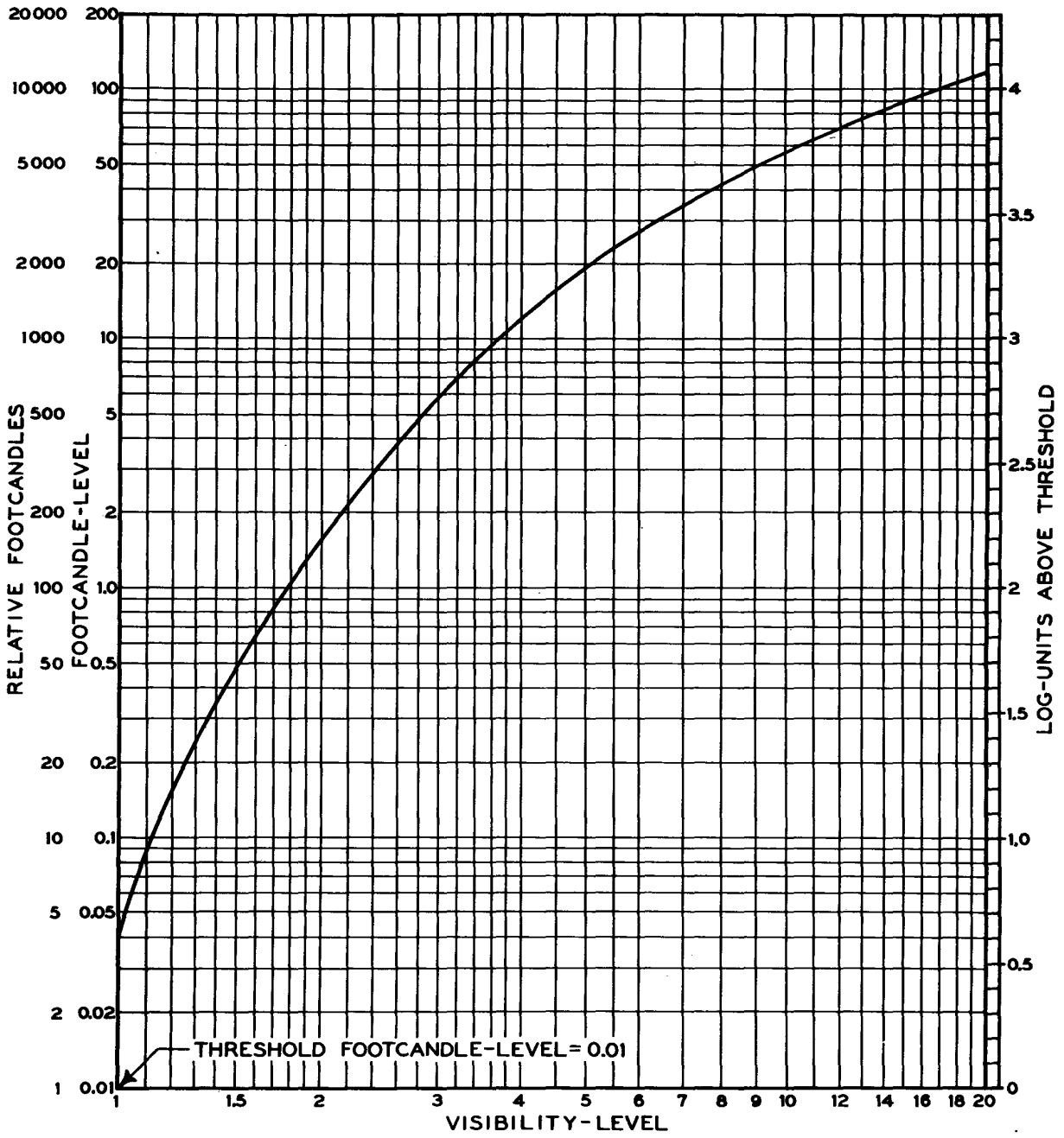

Figure 1. The relationship between visibility-level and footcandle-level for 8-point type. The values indicated by the outer left-hand scale are relative footcandles above the threshold footcandle-level. The right-hand ordinate represents equal logarithmic steps above the threshold footcandle-level.

TABLE I.—Relative Footcandles for Various Visibility-Levels and the Number of Log-Units Each Footcandle-Level Is Above the Threshold

Visibility Level	Relative Footcandles	Log-Units Above Threshold
Threshold	1	0
1.0	4	0.60
1.1	9	0.95
1.2	15	1.18
1.3	23	1.36
1.4	34	1.53
1.5	47	1.67
1.6	63	1.80
1.7	82	1.91
1.8	103	2.01
1.9	128	2.11
2.0	155	2.19
2.2	217	2.34
2.4	290	2.46
2.6	380	2.58
2.8	480	2.68
3.0	590	2.77
3.2	710	2.85
3.4	825	2.92
3.6	940	2.97
3.8	1075	3.03
4.0	1210	3.08
4.5	1560	3.19
5.0	1920	3.28
5.5	2300	3.36
6.0	2680	3.43
7.0	3480	3.54
8.0	4220	3.62
9.0	5000	3.70
10.0	5700	3.76
11.0	6300	3.80
12.0	6970	3.84
13.0	7600	3.88
14.0	8200	3.91
15.0	8800	3.94
16.0	9400	3.97
17.0	10000	4.00
18.0	10600	4.03
19.0	11100	4.05
20.0	11700	4.07

objects ranging in visual sizes from one to 20 minutes when viewed against a white background. They represent the logarithmic differences between the footcandle-levels required for successive visibility-levels of a specific test-object. For example, a 2-minute test-object requires 10 and 21 footcandles for visibility-levels of 2 and 2.5, respectively. The difference between the logarithms of these footcandle-levels is 0.32. Table II illustrates that for a specific difference of visibility-level, the log-unit difference between the footcandle-levels required for these visibility-levels is constant for a wide range in the sizes of objects. This is evidenced by the small variation in log-units across any line of Table II.

A visibility-level of one indicates that an object is just barely visible when viewed through the clearest portion of the gradients of the Luckish-Moss Visibility Meter. Since there is some absorption by this part of the gradient, the absolute threshold of visibility of the task when it is viewed without the visibility meter will be obtained with a lower footcandle-level. From available data it has been determined that the threshold illumination (footcandles) is approximately 0.64 log-unit below the illlumination required for a visibility-level of one. The values in the last column of Table II have been obtained by successive addition of the average values plus 0.64 and result in a series of log-units of illumination above the threshold footcandle-level for objects of various sizes. Comparing these values with those in the third column of Table I, it is evident that the latter may be used not only for the 8-point type, but for other visual objects and tasks.

The effect of various contrasts is illustrated by Table III, in which are summarized the logarithmic differences in footcandles-levels required for visibility-levels of 7 and 8 for objects varying in size

TABLE II.—Differences in Log-Units of Footcandles Above Threshold Between Successive Steps in Visibility-Levels for Various Sizes of Black Test-Objects Viewed Against a White Background

Visibility Level	Visual Size of Objects, Minutes											Average Difference	Log-units above Threshold
	1	1.5	2	2.5	3	4	5	7	10	15	20		
1													0.64
	1.08	1.00	—	—	—	—	—	—	—	—	—	1.04	
1.5													1.68
	0.50	0.52	0.54	0.52	—	—	—	—	—	—	—	0.52	
2													2.20
	0.34	0.34	0.32	0.34	0.31	0.33	—	—	—	—	—	0.33	
2.5													2.53
	—	0.24	0.25	0.24	0.28	0.24	0.23	—	—	—	—	0.24	
3													2.77
	—	0.31	0.32	0.31	0.30	0.31	0.33	0.31	0.30	—	—	0.31	
4													3.08
	—	0.20	0.20	0.19	0.20	0.22	0.21	0.20	0.20	0.20	0.20	0.20	
5													3.28
	—	0.14	0.15	0.16	0.14	0.14	0.15	0.14	0.15	0.15	0.15	0.15	
6													3.43
	—	0.12	0.11	0.12	0.11	0.12	0.10	0.11	0.11	0.10	0.12	0.11	
7													3.54
	—	0.09	0.08	0.08	0.09	0.08	0.08	0.09	0.08	0.09	0.08	0.08	
8													3.62
	—	—	0.12	0.12	0.13	0.12	0.14	0.12	0.12	0.12	0.13	0.12	
10													3.74
	—	—	0.10	0.10	0.09	0.09	0.08	0.10	0.10	0.10	0.09	0.09	
12													3.83
	—	—	0.13	0.13	0.12	0.12	0.14	0.13	0.13	0.14	0.14	0.13	
16													3.96
	—	—	0.09	0.09	0.11	0.11	0.10	0.09	0.09	0.08	0.09	0.09	
20													4.05

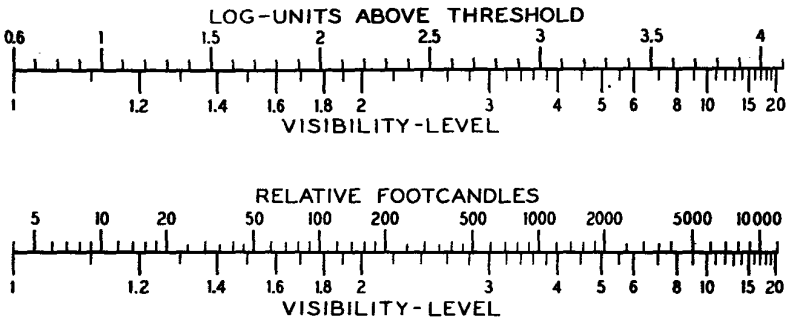

Figure 2. Scales for converting visibility-levels to relative footcandles and log-units above the threshold footcandle-level.

from one to 20 minutes and also varying in contrast from 5 to 95 per cent. The average log-difference is 0.08 with a variation from 0.07 to 0.10. There is no indication of a systematic variation due either to size or contrast. Similarly consistent data were obtained for other visibility-levels.

From Tables II and III it is evident that the values in Table I are valid for a wide range of visual objects or tasks of different size and contrast. The relationship between visibility and relative footcandles in Table I (or corresponding scales on the Luckiesh-Moss Visibility Meter) makes it possible to evaluate in terms of illumination (footcandles) the supra-threshold visibility of an extensive variety of visual tasks. Thus, the footcandle-level for a specific supra-threshold visibility-level, such as a visibility-level of 9, can be defined as being 5000 times the threshold footcandle-level or as being 3.7 log-units above the threshold-level. Furthermore, such a table or scale permits ready calculation of footcandle-levels necessary to obtain desired visibility-levels.

The determination of the footcandle-level required to obtain a desired visibility-level for a given visual object or task becomes a simple matter of determining how much an existing footcandle-level is above the threshold, and then computing the factor by which this existing footcandle-level must be increased in order to raise the object or task to the desired supra-threshold visibility-level. For example, suppose that the observed visibility-level of a specific task when illuminated with 10 footcandles is 1.9. From Table I it is found that this visibility-level corresponds to a relative footcandle-level of 128 or to 2.11 log-units above the threshold. It is desired to determine the footcandle-level that will raise the visibility-level of the task to 9, which corresponds to a relative footcandle-level of 5000, or 3.7 log-units of illumination above threshold. The ratio 5000/128 or 39 indicates the factor by which the existing illumination of 10 footcandles must be multiplied in order to raise the task to the desired supra-threshold visibility-level. Thus, in order to obtain the desired supra-threshold visibility-level of 9 it is necessary to provide 10 times 39 or 390 footcandles for this specific task. The same result is obtained with the scale of log-units. The difference between 3.7 and 2.11 is 1.59 which is the number of log-units that must be added to the logarithm of the existing footcandle-level. In other words, 1.59 added to 1.00 (the logarithm of 10) equals 2.59, which is the logarithm of 390 and the desired illumination is 390 footcandles.

Either the scale of relative footcandles or the logarithmic scale can be applied to the Luckiesh-Moss Visibility Meter. Both yield identical results, as is illustrated by the preceding example. It is evident that the scale of relative footcandles is con-

TABLE III.—Differences in Log-Units Between Footcandle-Levels Required for Visibility-Levels of 7 and 8 for Test-Objects of Various Sizes and Contrasts

Per Cent Contrast	Size										
	1	1.5	2	2.5	3	4	5	7	10	15	20
95	—	0.10	0.09	0.09	0.07	0.08	0.08	0.09	0.08	0.08	0.08
90	—	0.10	0.09	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08
80	—	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.08
70	—	0.09	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08
60	—	—	0.09	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.08
50	—	—	0.09	0.10	0.10	0.08	0.08	0.08	0.07	0.08	0.08
40	—	—	0.09	0.09	0.10	0.09	0.09	0.08	0.07	0.08	0.07
30	—	—	—	0.09	0.10	0.09	0.08	0.08	0.08	0.08	0.08
20	—	—	—	0.09	0.10	0.10	0.09	0.09	0.07	0.08	0.07
15	—	—	—	—	0.09	0.10	0.09	0.09	0.07	0.08	0.08
10	—	—	—	—	—	0.08	0.09	0.08	0.08	0.08	0.08
5	—	—	—	—	—	—	0.07	0.08	0.07	0.08	0.08

TABLE IV.—Comparison of Log-Units of Illumination Above Threshold Footcandle-Level and the Relative Footcandles for Samples of Printed Matter (Black Print on White Paper) as Obtained by Direct Observation and by the Use of a New Scale for the Luckiesh-Moss Visibility Meter

Task	Visibility-Level	Footcandle-Level	Threshold Footcandle-Level	Log-Units Above Threshold		Relative Footcandles	
				Observed	New Scale	Observed	New Scale
A. Samples from a technical publication							
8-point type	2.80	10	0.022	2.66	2.68	455	480
6-point type	2.30	10	0.042	2.38	2.40	238	250
B. Samples from three dictionaries							
Defined Words							
Sample 1	2.28	10	0.036	2.44	2.40	278	250
Sample 2	3.49	10	0.013	2.89	2.93	770	850
Sample 3	2.83	10	0.024	2.62	2.68	416	480
Definitions							
Sample 1	2.36	10	0.026	2.59	2.43	384	290
Sample 2	2.76	10	0.023	2.60	2.66	400	450
Sample 3	2.45	10	0.026	2.59	2.50	384	360

siderably easier to use, since it involves easily calculated ratios, whereas the log-unit scale involves odd exponentials. Scales for converting the present scale of visibility-levels of this visibility meter to relative footcandles and log-units above the threshold are presented in Fig. 2.

A further check of these new scales is presented in Table IV. These data were obtained by a skilled observer possessing average normal vision. The visibility-levels of several samples of printed matter were determined when the samples were illuminated with 10 footcandles. The threshold footcandle-levels were obtained by reducing the illumination to the point where the observer could just barely read the printed matter. The log-units of illumination above the threshold footcandle-level were obtained (a) by determining the number of log-units that 10 footcandles are above the observed threshold footcandle-level and (b) from the upper conversion scale of Fig. 2. For example, for the sample of 8-point type printed with black ink on white paper the difference between the logarithms of 10 and 0.022 is 2.66. From the upper conversion scale of Fig. 2, the number of log-units above threshold, corresponding to a visibility-level of 2.8, is 2.68. Similarly, the relative footcandles were obtained from the observed footcandle-levels and from the lower conversion scale of Fig. 2. It is seen that the ratio between 10 footcandles and the threshold footcandle-level of 0.022 is 455 which is in satisfactory agreement with the value of 480 obtained from Fig. 2 for a visibility-level of 2.8. The data obtained with other samples of printed matter indicate correspondingly good agreement between observed values and those obtained from the calibration data of the visibility meter.

From the foregoing it appears evident that the new scale of relative footcandles is a convenient and useful addition to the Luckiesh-Moss Visibility Meter for determining footcandle-levels corresponding to desired visibility-levels. Also, when so desired, the visibility-level of a task may be expressed either in terms of relative footcandles above the threshold or as log-units above the threshold footcandle-level. When incorporated in the meter, the new scale will require no charts or tables for its use. However, it still will be necessary to take the necessary precautions when using the meter and to apply the personal correction-factor to compensate for variations from the standard observer. These have been adequately described elsewhere.[2]

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