Visual Performance

Under Conditions of

TRANSIENT ADAPTATION

By Robert M. Boynton and Norma D. Miller

INTRODUCTION—Making visual adjustment to sudden changes in the amount of light reaching the eye is one of the inescapable problems of modern life. The driver who emerges suddenly from a light tunnel onto a dark highway, the airplane pilot who after looking out a dark window must suddenly read a lighted instrument panel, the factory technician who moves his eyes from a brightly illuminated inspection area to a dark part of a plant—all have special problems of maintaining good visual performance.

And it is up to the professional lighting designer to plan the lighting equipment for their special problems, as well as for other artificially lighted working and living areas, so that visual adaptation to light changes can take place in a manner least likely to reduce visual efficiency.

To do this job effectively, lighting engineers need to know more about the reaction of the eye itself to varying light conditions and changes of brightnesses of surfaces seen. The minimum standards for changes of brightness established to date are based on research done in 1932, and since that time new research techniques have been developed to measure the functioning of the eye.

Accordingly, the Illuminating Engineering Research Institute in 1959 began its sponsorship of a research project at the University of Rochester to carry out investigations necessary to develop a better basis for specifying suitable brightness ratios for interior use. This project is entitled "Visual Performance Under Conditions of Transient Adaptation." What follows is a preliminary report of this work, which is still in progress.

The experimenters wanted to find out what happens to visual performance when a person suddenly moves his glance from one spot in a visual field to another where a different level of brightness exists. This is a frequent occurrence in the day-to-day situation, where we make continual changes of eye position with respect to our visual environment, moving our eyes from one object to another and then back again. In a school situation, for instance, the student may look from a bright piece of white paper on his desk to a darker blackboard from which he is copying material, and then back again.

It has long been known by lighting engineers that a shift in eye movement from a dark to light surface and back again has a strong (and deleterious) effect upon visual acuity. Engineers faced with the task of designing efficient offices, adequate school buildings, and safe and productive industrial plants have traditionally paid a good deal of attention to brightness ratios between task and surrounding environment. The study described here is a step toward the more exact determination of what these ratios should be. It was carried out at the University of Rochester by Dr. Robert M. Boynton, Professor of Psychology and Optics and Mrs. Norma D. Miller, Research Associate in Psychology.

THE WORK to be described in this report concerns the visibility changes produced by sudden increases or decreases in a prevailing luminance level. Such changes may occur in everyday vision either as a result of illumination changes in the visual environment, the movement of the eyes within a variegated visual field, or combinations of both. In the work to be reported, the eyes were held stationary while the luminance increment required for the threshold recognition of a test letter was determined at various times near the moment of luminance tran-

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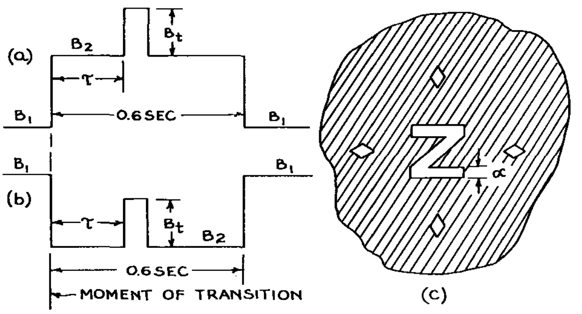

Figure 1. (a) Schematic representation of time sequence of events in stimulus presentation. Transition from level B_1 *to higher level* B_2 *is illustrated.*

(b) Same as (a) except that transition from level B_1 *to lower level* B_2 *is illustrated.*

(c) Appearance of screen during test-letter flash for one of the ten letters. Critical detail of letter size, α*, is defined as width of gap and is 1/5 the total size of letter. Diamonds are fixation spots.*

sition. It is to be expected that the contrast required for visibility should be lowest for the completely adapted eye and raised by any previous sudden change—whether up or down, and this was in fact the obtained result. The data provide a quantitative statement of the extent of these contrast variations for sudden luminance changes upward from 0.04 mL, downward from 40 mL, and in both directions from a point midway between these two on a logarithmic scale. Some preliminary data are also reported for higher luminances, and attention will also be given to the time course of recognition threshold changes between a restricted number of luminances.

The time course of threshold changes following a sudden decrease in prevailing luminance forms the beginning of the classical dark-adaptation curve. Threshold changes produced by sudden increases in prevailing luminance level have been studied by Crawford,[1] Boynton et al,[2-5] Battersby and Wagman,[6] and recently by Baker,[7, 8] who has also studied the decreasing case with the same subjects. These studies have involved the detection threshold of a circular disc as the criterion measure. Pupil size has been controlled, since the investigators have not been interested in engineering applications. Only Baker has investigated upward as well as downward luminance changes from and to levels other than complete darkness. We have deliberately used letter-recognition threshold and have not controlled size of the pupils.

Apparatus

Three commercial 35-mm slide projectors (Bell & Howell Robomatic 750) were adapted to provide the stimuli for the experiment. Two were equipped with double-bladed electromechanical shutters constructed from Ledex rotary solenoids which cut the beam one inch in front of the projector and provided a rise time at the center of the screen of 12 milliseconds as determined by oscillographic calibration. A cam-and-microswitch timer allowed the shutters to be operated accurately in various temporal sequences. Two of the projectors provided the adapting stimuli. Increases in prevailing adapting level were provided by adding the luminance provided by Projector 2 to that already supplied by Projector 1. Decreases in prevailing adapting level were provided by the sudden extinction of the luminance provided by Projector 2, leaving only that component of the total luminance provided by Projector 1. Slide holders allowing the insertion of neutral density filters were placed in front of each projector.

Projector 3 carried the test-letter slides. In addition to the appurtenances carried by the other projectors, a variable neutral density wedge allowed the luminance provided by Projector 3 to be varied in steps of any desired size.

For most of the work, the output of the projectors was viewed by reflection from a large screen (30 by 40 degrees of visual angle) painted matte white and having a reflectance of 92 per cent. Luminance calibrations were obtained by use of a Macbeth illuminometer. The test slides were made on Kodalith film providing very high contrast and low fog level.

Procedure

The subject was allowed to view the white screen with both eyes at luminance B_1, the pre-adapting luminance, for at least 5 minutes (see Fig. 1). Then, suddenly, level B_1 changed (up or down) to level B_2. We may call the time at which this occurred the *moment of transition.* Then, at some time *tau,* after the moment of transition, the test letter was briefly (30 milliseconds) superimposed on level B_2. Original level, B_1, was resumed exactly 0.6 second following the moment of transition. The subject then reported which of the ten letters, if any, he had seen. Fifteen to thirty seconds were then allowed to elapse (depending upon the size and direction of the transition from B_1 to B_2) and the cycle was repeated—this time with the luminance increment of the test letter reduced by 12.3 per cent (0.05 log unit). This procedure was continued until two consecutive incorrect letter-recognition judgments were made.

The *luminance threshold* of a test letter, for a given determination, was taken as that luminance increment (provided by the projector containing the transparencies of the letters) at which a letter was correctly recognized prior to two consecutive incorrect recognition judgments. This threshold luminance increment will be called B_t.

The *contrast threshold* of a test letter is calculated as B_t/B_2 and will be abbreviated C_t.

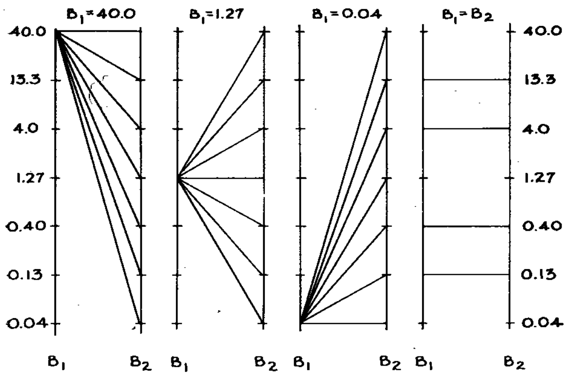

Figure 2. Schematic representation of the conditions of luminance change used in the experiment for tau = *0.3 second. These 25 conditions were repeated for each of four letter sizes.*

Experimental Design

Part A. A range of luminances from 0.04 mL to 40 mL was investigated with *tau* held constant at 0.3 second. Twenty-five experimental conditions were used which are illustrated in Fig. 2. B_1 was set at either 40, 1.27, or 0.04 mL for most of the conditions. The 40 mL condition of B_1 permitted only decreases, and the 0.04 mL condition only increases, in luminance level at the moment of transition. With B_1 set at 1.27 mL, changes could occur in either direction. In addition to the seven conditions of change for each of the three values of B_1, four additional conditions were employed, where $B_1 = B_2$ (no change in luminance level) for the four values of B_1 not already included as special cases under the other conditions. Two subjects were employed under all of these conditions.

Part B. For a limited set of values B_1 and B_2, the letter-recognition threshold was measured for values of *tau* ranging from —0.2 second (where the test letter is presented 0.2 second *before* the moment of transition) to 0.3 second (where the test letter follows the moment of transition by 0.3 second). The spacing of the steps of *tau* varied from 10 to 50 milliseconds.

Results

Part A. Luminance thresholds for each subject for four test letter sizes used under each of 25 conditions illustrated in Fig. 1 are given in Table I. These raw data are based upon at least two threshold determinations for each subject under each condition. The average data for the two subjects are shown in Fig. 3. The following remarks may be made about the nature of these curves:

(1) For the steady-state condition, where $B_1 = B_2$

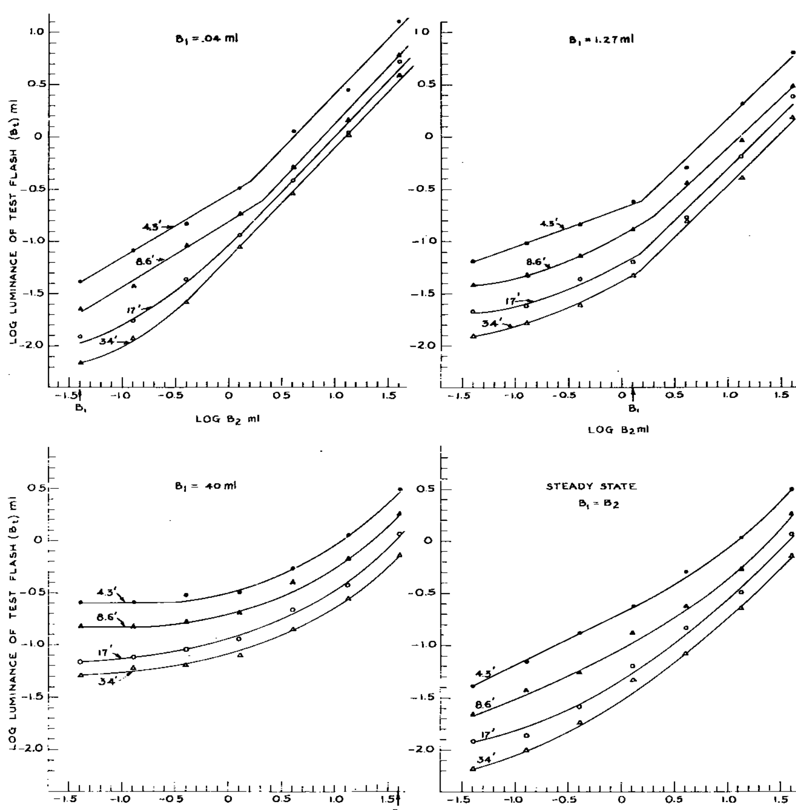

Figure 3. The letter recognition thresholds (B_t) *in log mL as a function of log* B_2 *(the level after transition). Each set of curves is for a different level of* B_1 *except for the set at the lower left, where* $B_1 = B_2$ *for each point (steady state). Parameter is the critical detail of the test letter in minutes of arc.* Tau = *0.3 second; data are mean values for two subjects combined.*

Table I—Threshold luminance (B_t) of test letters in log mL. Thresholds for each of two observers are shown together with mean values and calculated contrast threshold (C_t). All thresholds are for tau = 0.3 second.

	CRITICAL DETAIL = 4.3′				CRITICAL DETAIL = 8.6′			
B_1 = 40 mL	M.W.	L.W.	Avg	Log C_t	M.W.	L.W.	Avg	Log C_t
B_2 = 40 mL	.54	.46	.50	−1.10	.26	.28	.27	−1.33
13.3	.06	.06	.06	−1.06	− .25	− .09	− .17	−1.29
4.0	− .29	− .24	− .26	− .86	− .44	− .34	− .39	− .99
1.27	− .59	− .39	− .49	− .59	− .69	− .69	− .69	− .79
.4	− .54	− .49	− .52	− .12	− .84	− .69	− .77	− .37
.13	− .64	− .54	− .59	.31	− .84	− .79	− .82	.08
.04	− .59	− .59	− .59	.81	− .89	− .74	− .82	.58
B_1 = 1.27 mL								
B_2 = 40 mL	.86	.76	.81	− .79	.51	.47	.49	−1.11
13.3	.46	.21	.33	− .79	.01	− .10	− .04	−1.08
4.0	− .29	− .29	− .29	− .89	− .39	− .48	− .44	−1.04
1.27	− .65	− .59	− .62	− .72	− .88	− .90	− .89	− .99
.4	− .89	− .79	− .84	− .44	−1.09	−1.19	−1.14	− .74
.13	−1.04	− .99	−1.02	− .12	−1.34	−1.29	−1.32	− .42
.04	−1.29	−1.09	−1.19	.21	−1.44	−1.40	−1.42	− .02
B_1 = .04 mL	M.W.	L.W.	Avg	Log C_t	M.W.	L.W.	Avg	Log C_t
B_2 = 40 mL	1.06	1.14	1.10	− .50	.76	.81	.78	− .82
13.3	.41	.46	.44	− .68	.06	.26	.16	− .96
4.0	.01	.06	.04	− .64	− .34	− .24	− .29	− .89
1.27	− .49	− .49	− .49	− .59	− .79	− .69	− .74	− .84
.4	− .89	− .79	− .84	− .44	−1.09	−1.01	−1.05	− .65
3	−1.09	−1.09	−1.09	− .19	−1.54	−1.34	−1.44	− .54
04	−1.35	−1.43	−1.39	.01	−1.69	−1.62	−1.65	− .25
Steady State								
40	.54	.46	.50	−1.10	.26	.28	.27	−1.33
13.3	.02	.06	.04	−1.08	− .35	− .19	− .27	−1.39
4.0	− .36	− .23	− .29	− .89	− .70	− .55	− .62	−1.22
1.27	− .65	− .59	− .62	− .72	− .88	− .88	− .88	− .98
.4	− .83	− .94	− .88	− .48	−1.23	−1.30	−1.26	− .86
.13	−1.13	−1.19	−1.16	− .26	−1.47	−1.39	−1.43	− .53
.04	−1.36	−1.43	−1.39	.01	−1.69	−1.62	−1.65	− .25

	CRITICAL DETAIL = 17.0′				CRITICAL DETAIL = 34.0′			
B_1 = 40 mL	M.W.	L.W.	Avg	Log C_t	M.W.	L.W.	Avg	Log C_t
B_2 = 40 mL	.08	.06	.07	−1.53	− .12	− .16	− .14	−1.74
13.3	− .50	− .34	− .42	−1.54	− .54	− .54	− .54	−1.66
4.0	− .69	− .64	− .66	−1.26	− .94	− .74	− .84	−1.44
1.27	− .99	− .89	− .94	−1.04	−1.19	− .99	−1.09	−1.19
.4	−1.19	− .89	−1.04	− .64	−1.24	−1.14	−1.19	− .79
.13	−1.14	−1.09	−1.12	− .22	−1.29	−1.14	−1.22	− .32
.04	−1.29	−1.04	−1.16	.24	−1.44	−1.14	−1.29	.11
B_1 = 1.27 mL								
B_2 = 40 mL	.41	.36	.38	−1.22	.21	.17	.19	−1.41
13.3	− .14	− .24	− .19	−1.31	− .39	− .41	− .40	−1.52
4.0	− .74	− .80	− .77	−1.37	− .84	− .76	− .80	−1.40
1.27	−1.17	−1.24	−1.20	−1.30	−1.30	−1.34	−1.32	−1.42
.4	−1.39	−1.34	−1.36	− .96	−1.59	−1.63	−1.61	−1.21
.13	−1.64	−1.60	−1.62	− .72	−1.79	−1.76	−1.78	− .88
.04	−1.74	−1.58	−1.66	− .26	−1.94	−1.88	−1.91	− .51
B_1 = .04 mL	M.W.	L.W.	Avg	Log C_t	M.W.	L.W.	Avg	Log C_t
B_2 = 40 mL	.66	.78	.72	− .88	.56	.61	.58	−1.02
13.3	.01	.06	.04	−1.08	.01	.01	.01	−1.11
4.0	− .30	− .54	− .42	−1.02	− .54	− .56	− .55	−1.15
1.27	− .99	− .89	− .94	−1.04	−1.04	−1.09	−1.06	−1.16
.4	−1.34	−1.39	−1.36	− .96	−1.64	−1.54	−1.59	−1.19
.13	−1.84	−1.69	−1.76	− .86	−2.00	−1.89	−1.94	−1.04
.04	−1.94	−1.90	−1.92	− .52	−2.17	−2.17	−2.17	− .77
Steady State								
40	.08	.06	.07	−1.53	− .12	− .16	− .14	−1.74
13.3	− .49	− .49	− .49	−1.61	− .64	− .64	− .64	−1.76
4.0	− .83	− .83	− .83	−1.43	−1.09	−1.06	−1.08	−1.68
1.27	−1.17	−1.24	−1.20	−1.30	−1.30	−1.34	−1.32	−1.42
.4	−1.56	−1.61	−1.58	−1.18	−1.76	−1.73	−1.74	−1.34
.13	−1.88	−1.84	−1.86	− .96	−2.00	−1.99	−2.00	−1.10
.04	−1.94	−1.90	−1.92	− .52	−2.17	−2.17	−2.17	− .77

and there is no change in prevailing luminance level, the functions for threshold letter recognition have the same general shape as do such functions for simple detection. For the highest luminance levels used, a unit slope of these functions is approached, which means that the contrast threshold, which drops throughout most of the range, is approaching a constant value. In subsequent experiments we have extended this range to about 3.5 log mL without finding significant departures from unit slope.

(2) For the *tau* = 0.3 second condition, less than unit slope is recorded for (a) all segments of functions below $B_2 = 0$ log mL, and (b) all values of B_2 less than B_1. A slope of approximately unity is the general rule for all values of B_2 greater than B_1, excepting values of B_2 less than 0 log mL. The significance of the slopes equal to unity deserves emphasis: it means that the contrast threshold is constant over the indicated range of luminance levels.

Perhaps a more meaningful way to plot the data is in terms of log contrast threshold (C_t) *vs* log B_2, since in an ordinary visual environment contrast remains constant despite changes in illumination. These calculations have been carried out and the curves are plotted in Fig. 4. The meaning of these curves will be explained in terms of one of the points —the one marked with an arrow. This point is found at an ordinate value of about 0.10. This log contrast value, corresponding to about 1.25 (125 per cent), means that the test letter increment must be 1.25 times as great as B_2 when the letter appears exactly 0.3 second following a transition from B_1 (40 mL) to B_2 (0.4 mL). This value should be compared to that of the lowest curve, which shows the contrast which will be required for recognizing the test letter after adaptation is complete. The latter value is about —0.77 on the log scale, corresponding to a contrast of about 0.16 (16 per cent). Therefore, the transient threshold is nearly eight times higher than it will become following complete adaptation to the new level.

It should be noted that the effect of suddenly changing adaptation level upward is not necessarily to reduce the contrast threshold. This may be seen for the $B_1 = 0.04$ mL in the same figure (as an example). All changes from this originally low adapting level produce an increase in performance (decrease in threshold contrast) at $T = 0.3$ second. The new thresholds, nevertheless, are substantially higher than they will become following complete adaptation. In this sense, then, increasing the prevailing level is not so damaging as decreasing it, since the deleterious effects of transient changes appear to be superimposed upon the beneficial effects generally associated with higher luminance levels. Nevertheless, it should be noted in the example just cited that the optimal increase is a factor of about 10 to 30 (depending upon letter size), which produces the minimum contrast threshold at the new level. Greater increases than this produce relatively higher contrast thresholds.

From the foregoing, it should be clear that the fair way to evaluate the effect of the transient changes is not in terms of the change in contrast threshold from that achieved at the original level, but rather in terms of the ratio between the transient contrast threshold at the new level to what it will become following complete adaptation to this new level. Let us call this factor ϕ, for convenience.

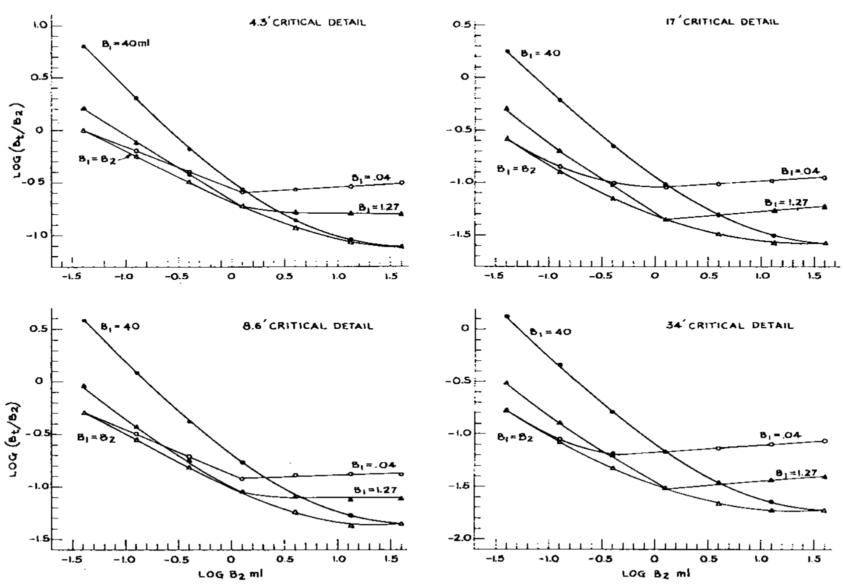

Figure 4. Log contrast thresholds for letter recognition (B_t/B_2) *as a function of log* B_2. *Each set of curves is for a different letter size as indicated. The parameter is the level of* B_1 *prior to the change to* B_2. *Contrast values have been calculated from smooth curves drawn through points shown in Fig. 3.*

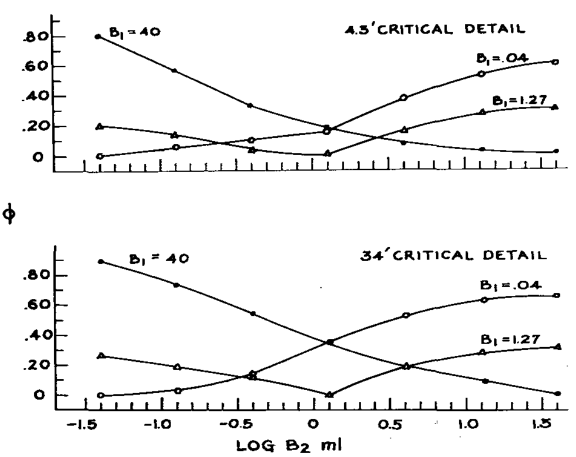

Figure 5. Values of ϕ (transient contrast threshold divided by steady-state contrast threshold) derived from data of Fig. 4.

$$\phi = \frac{B_t/B_2\ (\text{transient})}{B_t/B_2\ (\text{steady-state})} = \frac{B_t\ (\text{transient})}{B_t\ (\text{steady-state})}$$

In Fig. 5, ϕ is plotted as a function of B_2 for the various levels of B_1 employed and for the two extreme letter sizes used. These values are also given in Table II for all four letter sizes. These figures suggest that the effects of increasing and decreasing the prevailing level are roughly equivalent as thus evaluated, which leads to still a different way of expressing the results. In Fig. 6, ϕ is plotted against the factor by which the prevailing adapting level is changed, whether upward or downward. The three curves plotted represent the maximum, minimum, and mean values for all conditions investigated (16 values for the left-hand nine points, 8 values for the remainder). For engineering applications, the uppermost curve would probably be the safest to use, since it is indicative of the largest deleterious effects measured.

For some purposes, it might be convenient to calculate the increase in letter size that would be required, during the transient state, to maintain a contrast threshold as low as that which would obtain later for a given smaller letter after total adaptation. Examination of the data so far obtained, especially for the two smaller letter sizes, suggests that an approximate reciprocity obtains between letter size and contrast threshold. Doubling the letter size approximately halves all threshold values, whether under the steady-state or the transient condition. If we let ϕ' represent the factor by which the letter size must be multiplied in order to maintain the same contrast threshold during the transient state as will be achieved later, then it is approximately true that $\phi = \phi'$. Example: If the contrast threshold is twice as high under the transient condition as it will later become (for a constant letter size) then it is approxi-

Table II—Values of log ϕ (transient contrast threshold divided by steady-state contrast threshold at new level) arranged in groups according to the absolute difference between B_1 and B_2.

Magnitude of Change from B_1 to B_2 (log units)	Letter Size (α)	$B_1 = 40$ $B_1 > B_2$	$B = 1.27$ $B_1 > B_2$	$B = 1.27$ $B_1 < B_2$	$B = 0.04$ $B_1 < B_2$
0.5	4.3	.03	.03	.15	.06
	8.6	.10	.06	.14	.06
(3x)	17	.08	.13	.20	.06
	34	.09	.12	.19	.03
1.0	4.3	.06	.14	.27	.10
	8.6	.17	.14	.25	.10
(10x)	17	.20	.22	.30	.17
	34	.20	.18	.28	.14
1.5	4.3	.18	.20	.30	.15
	8.6	.29	.26	.25	.12
(30x)	17	.35	.28	.34	.33
	34	.35	.27	.32	.36
2.0	4.3	.33	----	----	.37
	8.6	.45	----	----	.32
(100x)	17	.50	----	----	.49
	34	.54	----	----	.53
2.5	4.3	.56	----	----	.52
	8.6	.64	----	----	.48
(300x)	17	.67	----	----	.59
	34	.73	----	----	.63
3.0	4.3	.80	----	----	.60
	8.6	.87	----	----	.48
(1000x)	17	.83	----	----	.62
	34	.89	----	----	.66

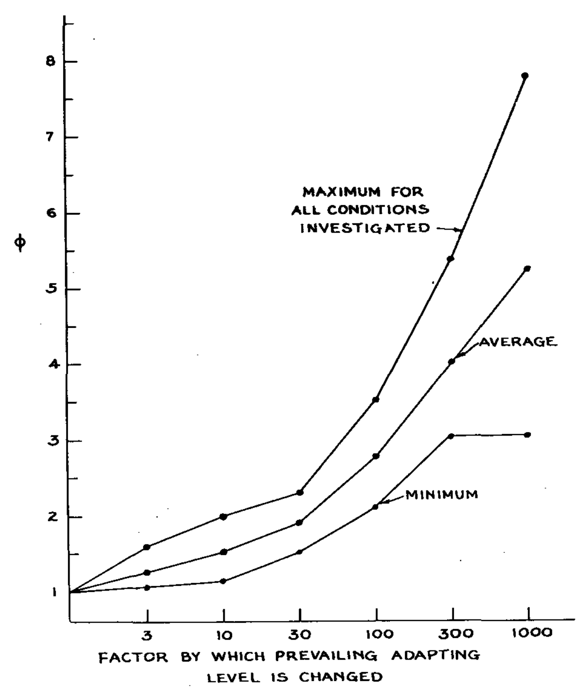

Figure 6. Factor ϕ (transient contrast threshold divided by steady-state contrast threshold) vs *absolute factor of change (semi-log plot). Maximum, minimum and average values are given, taken from Table II.*

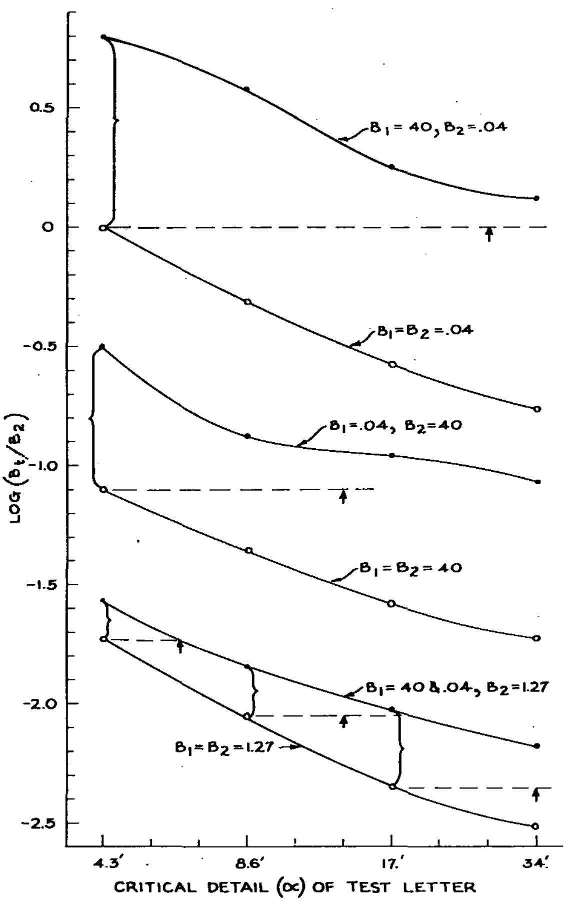

Figure 7. Log contrast thresholds for letter recognition (B_t/B_2) *as a function of letter size (log scale). Lowest pair of curves has been displaced downward by one log unit. Explanation of arrows and dotted lines in text.*

mately true that the use of a letter twice as large under the transient condition will maintain the visibility of the test letter without contrast change.

This generalization, however, breaks down for larger letter sizes and must not be used for initial letters having a critical detail larger than 8.6′ nor for predicted letter sizes larger than 8.6′. Examples are shown in Fig. 7. The upper pair of curves is for $B_1 = 40$ mL and $B_2 = 1.27$ mL. The upper curve is for the transient contrast threshold, the lower for the steady-state. Here we see that for a 4.3′ letter, the transient threshold is 0.8 log mL, the steady-state threshold 0.0 log mL. The difference, 0.8 log mL, should be producible by the $\phi = \phi'$ argument by an increase in letter size of 0.8 log unit and a contrast of 0.0 log mL. The arrow shows the letter size predicted, which is somewhat too small. Other curves in Fig. 7 are based on the same type of graphical analysis and lead to the same conclusion. The extent to which the rule holds for letter sizes smaller than 4.3′ remains to be tested in future experimentation. We offer it here only as a general rule of thumb which will typically slightly underestimate the actual letter size required to maintain threshold visibility.

Part B. In Fig. 8, letter-recognition thresholds are shown as a function of *tau* over range from *tau* = —0.2 to *tau* = +0.3 second. Data for three subjects are plotted to illustrate that individual differences are small, and that conclusions drawn from examination of data from one or two young normal observers are likely to apply to a larger population of young normals. Also shown are thresholds for circular

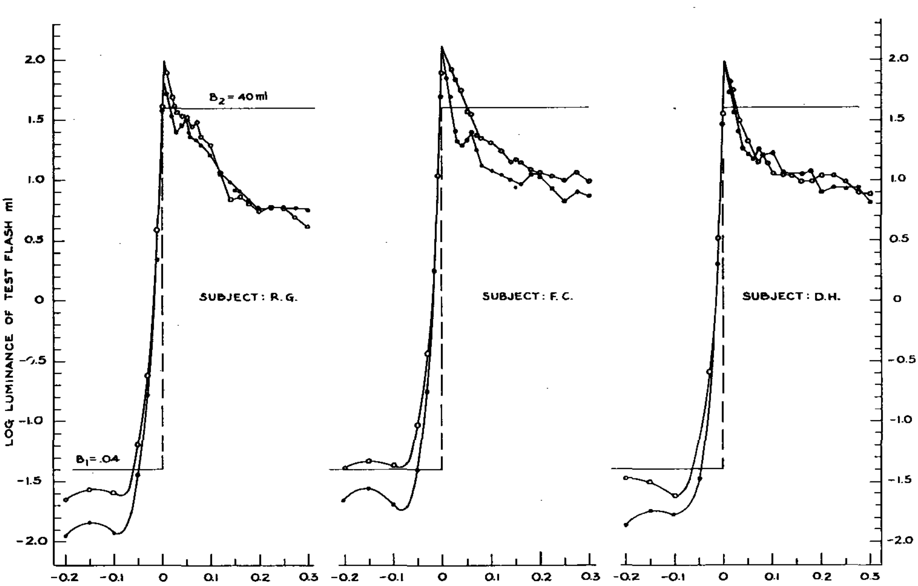

Figure 8. Letter-recognition thresholds (B_t) *in log mL as a function of* tau *for* $B_1 = 0.04$ *mL and* $B_2 = 40$ *mL. Also shown are detection thresholds for a circular test spot having the same total subtence as the test letter.*

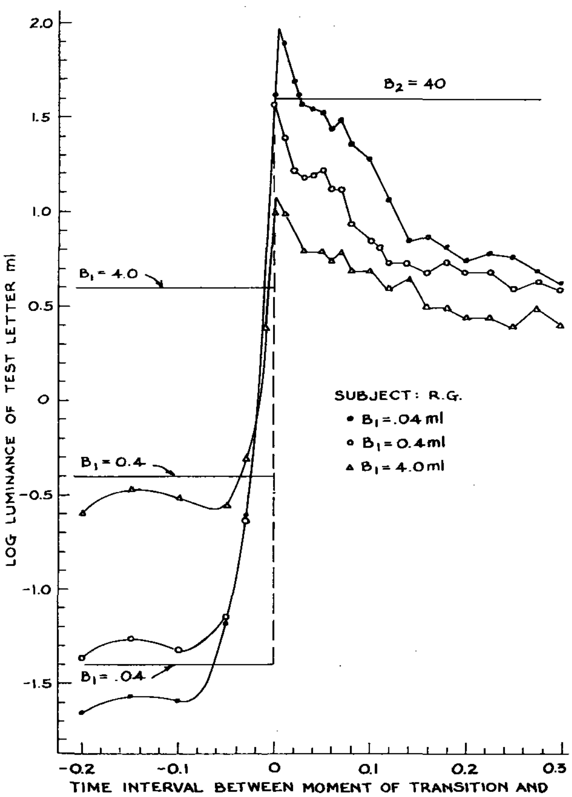

Figure 9. Letter-recognition thresholds (B_t) *in log mL for three values of* B_1 *and* B_2 *= 40 mL, as a function of* tau.

nashes, to be discussed below. It is of interest to note that the threshold drop that occurs during the first 0.3 second following the moment of transition is on the order of 1 log unit. Thus the factor ϕ would have to be multiplied by about 10 in order to determine the visibility loss at the moment of transition. Fig. 9 shows letter-recognition thresholds as a function of *tau* for three different amounts of luminance change at the moment of transition. Whereas B_2 is always 40 mL, B_1 has been varied from 0.04 mL to 4.0 mL with one intermediate step. These curves are quite comparable to ones previously published by Boynton and Kandel, and show that the amount of threshold elevation is reduced as the level of B_1 is increased. Note, however, that the threshold difference between *tau* at peak and *tau* = 0.3 second is reduced from about a factor of 10 (2.0 log unit) to a factor of about 5 (0.7 log unit).

We are not sure whether the "fine structure" on these *tau* functions is fact or artifact. Further work with improved equipment will be necessary to establish the answer.

Fig. 10 shows what happens at the moment of transition when B_2 is less than B_1. These curves confirm the fact that there is a small but significant threshold rise which occurs just before the moment of transition, and then a rapid threshold drop. At a value of *tau* of about 0.075 second, there is a break in the function which has been reported previously by Baker, though his data show it nearer to 0.20 second. Baker's data show that the threshold at the moment of transition is within 0.3 log unit of the steady-state threshold to level B_1. The contrast threshold at the moment of transition can therefore be estimated from the steady-state values given in Fig. 4. Example: In Fig. 4 (upper left-hand curve), for $B_1 = 40$ mL and $B_2 = 0.04$ mL, the threshold contrast value is given as 0.8. This, of course, is for *tau* = 0.3 second and we wish to find this value for *tau* equal to zero. To do so, we need merely to refer to the steady-state curve of Fig. 3 (upper-right-handmost point for $B_1 = B_2$, $\alpha = 4.3$) where we find that $B_t = 0.5$ log mL. Referred to level B_2 (−1.4 log mL), this resulting contrast value is 1.9. This is about 1.1 log units higher than the contrast threshold for $T = 0.3$ second, in reasonable agreement with the results shown on the *tau* curves.

Because of the considerable amount of work that has been done on transitional thresholds using circular test spots, it is of importance to determine the extent to which the choice of letters as test objects changes the results from what would be obtained using a simple circular test object. In the latter case, the task is changed from one of letter recognition (where the experimenter can rate the subject as being right or wrong) to detection threshold (where the experimenter has no such check). For the condition $B_1 = 0.04$ mL and $B_2 = 40$ mL, these experiments have been carried out with three subjects and a variety of values of *tau*. Results are shown in Fig.

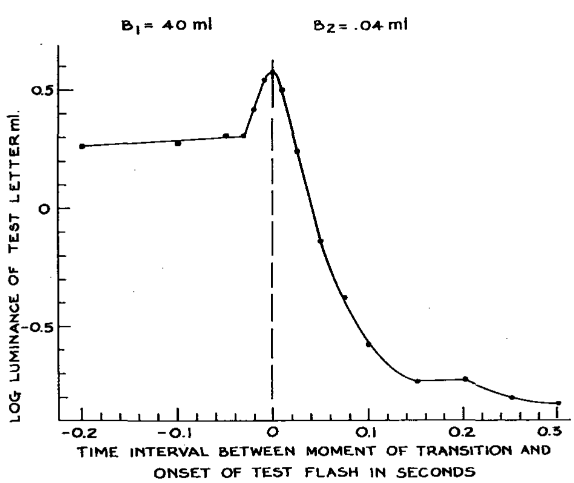

Figure 10. Letter-recognition thresholds (B_t) *in log mL where* B_2 *is less than* B_1 *(transition from 40 to 0.04 mL), as a function of* tau.

8, where the somewhat startling conclusion emerges that there is only a small difference between the two functions when a 42′ diameter circular flash is compared to the 8.6′ (critical detail) Sloan-Snellen letters which can be considered to be circumscribed within a circle of 42′ diameter. The slight difference between the curves may be due simply to the greater amount of total flux in the circle (a factor of about two). When this is taken into account, the letter thresholds are generally a bit lower than the circle thresholds—a somewhat perplexing conclusion. The result, however, accords with the subjects' reports: If the letter can be seen at all, it can usually be correctly recognized. The result may also concern the fact that detection thresholds have previously been found to be related to the ratio of perimeter to area; in other words, the more border which is present for a target of a given area, the lower will be its threshold. A circle, of course, is the most compact of all possible figures in this sense.

For our purposes, it is perhaps more important to conclude simply that results generated by means of letter-detection thresholds may be generalized to simple detection threshold situations and vice versa. We have found, actually, that the letter-recognition thresholds are easier to obtain and more stable than the detection thresholds and we plan to continue using them primarily for this reason.

Discussion

The choice of *tau* equal to 0.3 second for most of our work seems to have been a reasonable one. Whether B_2 is greater or less than B_1, the events which occur during the first 0.2 second or so following the moment of transition are so fast that slight errors of timing would result in large errors of measurement. After 0.3 second, events are more stable and, furthermore, if one were to employ the data obtained to predict for conditions where *tau* is 0.5 second, or even 1.0 second, the extrapolation would not be seriously in error. Also, when $B_2 < B_1$, for very small values of *tau*, the level of B_2 has relatively little effect on the threshold obtained. Baker has shown this very nicely for circular target recognition where he has found that the instantaneous threshold (*tau* equals zero) is not altered at all once B_2 reaches a value which is only slightly below that of B_1. Examination of our data (see Fig. 3) reveals that the level of B_2 does influence the threshold in a continuous fashion at least until B_2 becomes only 1/100 as large as B_1.

It would be of considerable interest to extrapolate our work to higher values of B_2. From the work of Blackwell, it appears likely that the steady-state contrast threshold will not change appreciably at very high values of B_2. Many of the transient contrast thresholds, however, appear to rise with increasing values of B_2, and although the rate of rise appears constant, we cannot be certain that it will actually continue to rise at this rate for still higher levels. We have done some exploratory work which suggests that the slope of this function may rise at even a faster rate for much higher levels.

In the application of our results to practical situations, it must be recognized that our data do not necessarily apply to an older subject population, nor to those with initially substandard vision. For the normal young adult, however, we can now offer conclusions about the effects of sudden illumination changes upon visual performance. These generalizations:

(1) are restricted to luminance changes in the range from 0.4 to 40 mL.

(2) use, as a measure of visual performance, the contrast required for threshold recognition of a test letter seen against the background provided by the new level, exactly 0.3 second following the transition from the first level to the second.

With these restrictions in mind, we may state that:

(1) evaluated in terms of visual performance at the initial level, sudden luminance changes upward do not necessarily decrease performance at the new level. If the initial level is low, performance at the new level is generally better or no different from that at the initial level. If the initial level is moderately high, performance at the new level may be slightly poorer.

(2) evaluated in terms of visual performance after total adaptation to the second level, sudden luminance changes always decrease visual performance. Although the underlying mechanisms are probably quite different, changes upward are roughly equivalent in their effects to changes downward as thus evaluated. The factor by which the contrast threshold of the test letter is elevated during the transient state is given by Fig. 6 and is no greater than eight for a thousandfold change in the initial level.

(3) for small letters, the letter size (linear) and contrast are roughly reciprocal. This means, for example, that a transient condition which elevates the contrast threshold by a factor of two (compared to what it will later become) will also increase by a factor of two the threshold size of letter required at a given contrast (compared to the letter size which will later become necessary for threshold recognition). For larger letter sizes, this rule under-

predicts the amount of increase in letter size necessary to maintain visibility at a given contrast.

Although we have, in this paper, attempted to restrict our comments to the facts which might be useful in the practice of illuminating engineering, a few comments concerning the authors' conception of *why* the results turn out as they do are perhaps in order.

When the visual system is suddenly confronted with an increase in the prevailing level of illumination, a burst of activity occurs in the retina of the eye which is transmitted from the eye to the brain—activity which signals that an upward change has occurred in the prevailing illumination level. When one attempts a visual task during this transient phase, relatively more contrast (or a larger target) is required because the system is already busy handling information pertaining to the illumination change. The greater the illumination change has been, the greater will be the activity level in the system, and therefore the greater must be the contrast (or size) of a target which one is trying to see during this period. As time goes on, this prevailing level of activity caused by the illumination change subsides until finally the system is handling only information pertaining to the steady state (which produces minimal signals). Except for very high levels, where complications occur which need not concern us here, the final steady-state thresholds will be the lowest obtainable.

It is, however, also true that the visual system works better, so far as acuity and contrast discrimination are concerned, at high levels than at low. There have been many theories advanced to account for this, none of which has received complete support, and which are not really important for the present discussion. When one goes suddenly from a low level of illumination to a higher one, performance during the transient phase at the new level may actually be better than it was during the steady state at the original level—this because of the general advantage of higher levels and despite the deleterious effects peculiar to the transient condition. The latter are shown by a still further improvement in performance until the steady state is achieved at the new level.

When the visual system is suddenly confronted with a *decrease* in the prevailing level of illumination, there may or may not be an appreciable signal sent through the visual system. (There is evidence that sudden increases are more effective than sudden decreases in arousing visual responses in the human.) The principal factor which limits visibility shortly after illumination decrease, however, is probably the state of sensitivity of the system. After steady-state exposure to a high level, the visual system is desensitized, partly because some of the available photosensitive pigment within each receptor has been bleached and rendered inactive (insensitive to further light stimulation) and partly for other reasons not yet well understood. A considerable amount of time is required before full sensitivity will be reached at the lower level. The process involved is known as dark adaptation and has been studied by many investigators.

Thus, as we go from a high level to a lower one, the system is still desensitized photochemically for a while; the transient thresholds therefore are higher than they will eventually become. Thus there are two factors—the generally poorer performance of the visual system at lower levels, and the failure to have allowed sufficient time for complete dark adaptation—which combine to mean that a sudden decrease in the prevailing luminance level will *always* reduce contrast-discrimination performance. Thus, we find without exception that the contrast required for letter recognition is always increased by a sudden decrease in prevailing illumination level.

The fairest way to evaluate performance, in either case, is in terms of what it eventually will become at the new level, since we are interested here in the effects of transient changes and not in the effects of light levels *per se*. Related to a practical example, we might be concerned with what happens as a child looks from his brightly illuminated paper on his desk to a dark blackboard; and we find (to a first approximation) that the deleterious effect of the sudden change is independent of the direction in which the change is made, though the threshold contrast of a task on his desk will in fact be lower than that for a task on the blackboard because of the higher light level on the desk. This equivalence is only rough and is obviously fortuitous. Still, it is approximately true, and we include Fig. 6 not with the feeling that it has any deep scientific significance, but rather in the hope that our data, in this form, may most readily find engineering applications.

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