TRANSITIONAL ADAPTATION IN TUNNEL LIGHTING

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The phenomenon of transitional adaptation concerns the changes in visibility resulting from sudden increases and decreases in the prevailing luminance level of the visual field. These changes occur when the individual changes his point of regard to surfaces having different luminances, when viewing a variegated surface, or simply as the result of illumination changes occurring naturally in the visual environment. As variation in the visual field is necessary for vision to exist, the research on transitional adaptation has addressed itself to the question of how much variation of luminance should be permitted within the field of view to maintain adequate visibility.

Transitional adaptation has relevance to the visual problems of driving and highway illumination. One can consider at least one of the tasks of the driver as being an information-receiving component in a man-machine-environment system. Since, a considerable amount of information input is in the form of visual signals from the roadway as well as the instrument panel, any sudden change in the prevailing luminance level which might produce a loss in visibility could be detrimental to the overall performance of the driver. The losses in visibility resulting from changes in the prevailing luminance level are relevant to a number of lighting problems in the lighting of tunnels. Sudden transitions in tunnel lighting are able to produce a "black-out" effect at the entrance of a tunnel, create blind spots upon entering or exiting a tunnel, and a possible slowing down of traffic through the tunnel. During the day the driver is often confronted with a sudden decrease in illumination on entering a tunnel or underpass and a sudden increase on exiting. At night the reverse situation is usually the case. In addition, discontinuous or spaced lighting fixtures within a tunnel might produce a flickering effect, and this can also be a case of transitional adaptation (a series of rapid changes in luminance level) with a resultant loss in visibility.

Although answers to certain specific problems in tunnel lighting and transitional adaptation may in some cases be lacking research has been done which approaches these situations. The research described herein has been carried out primarily by Dr. Robert M. Boynton and his associates (Boynton & Miller, 1963; Rinalducci, 1964; Boynton, 1967; Boynton, Rinalducci, & Sternheim, 1969; Boynton, Corwin, & Sternheim, 1970) at the University of Rochester. Investigations of transitional adaptation are being continued at the University of Virginia under the direction of this researcher. These investigations have been sponsored by the Illuminating Engineering Research Institute.

Visual adaptation is the process whereby the eye adjusts to changes in luminance level over time. Some of these changes in sensitivity take place in a few hundred milliseconds, while others take place in several minutes to an hour. Transitional adaptation is of course concerned with the faster changes and is probably neural in nature. The adaptation which takes place over a longer period of time (up to an hour or more) appears to be more closely related to the concentration of photopigment in the receptors of the eye.

Transitional adaptation might be described in the following way (Boynton & Kandel, 1959). When the eye is presented with a sudden increase or decrease in the prevailing level of illumination, a transient burst of activity occurs in the retina of the eye which is transmitted to the brain signaling this change. If the individual is asked to perform a visual task at this time such as the recognition of a test letter, a greater contrast between the letter and the background will be required to recognize the letter, because the visual system is busy handling information related to the change in luminance level. Thus, the activity produced by the change "masks" the test letter. The greater the change in luminance level the greater the contrast necessary to recognize the test letter. Eventually, the activity due to the sudden change subsides and the eye reaches a state of complete adaptation (termed the steady-state condition).

The problem of transitional adaptation has been simulated in the laboratory. In one procedure, the test-letter target is presented in a known location and at a known or fixed time relative to a change in the prevailing luminance level. The time between the moment of transition from a dark background to a brighter one or vice versa to the presentation of the test letter is designated by the Greek letter tau (τ). This procedure is shown schematically in Fig. 1. Here the prevailing luminance level called B_1, changes to a new level B_2. An upward change is shown in Fig. 1a and a downward change in Fig. 1b. Targets consisting of flash-illuminated, equally-discriminable Sloan-Snellen test letters are presented at time tau after the moment of transition from B_1 to B_2, and are seen by the observer superimposed on the changing background field between a diamond-shaped array of four points of light (shown in Fig. 1c).

The results of these investigations have typically been interpreted in terms of the differences between the contrast threshold of the test-letter flash in the transient state of adaptation and that following complete adaptation to the new level. Contrast threshold is defined as the just-perceptible increment of light in the test-letter flash, B_t, divided by the background against which it was presented, B_2. Visibility loss is expressed by the Greek letter Phi (Φ). It is equal to B_t' (the test-flash increment in the transient state) divided by B_2. This quantity is divided by B_t (the test-flash increment in the steady state) divided also by B_2. This relation reduces to B_t' divided by B_t which are in the same units, and therefore provides the dimensionless ratio shown below.

$$\Phi = \frac{\text{increment threshold 0.3 sec. following change from } B_1 \text{ to } B_2}{\text{final (steady-state) increment threshold at level } B_2}$$

If it turns out that the value of Phi is ten then this would mean that it would take ten times the amount of light in the transient condition to recognize a test letter than it would take in the steady-state condition. As log Phi is usually the value determined, this would be equal to 1 in the present example. Thresholds are determined by presenting the test letters repeatedly and raising or lowering their luminance in order to find that level at which they are recognized 50% of the time.

The general procedure and the results of some of the experiments conducted at the Universities of Rochester and Virginia are examined below. Fig. 2 shows the apparatus used in the first two experiments to be described. This apparatus provided a central adapting field upon which was superimposed a test-letter flash. The adapting field was at the center of a surround field provided by an integrating sphere into which the subject looked. An electronic timing system allowed the central field and the surround to change simultaneously and presented the test-letter flash. Flashed opal (milk glass) or ground glass screens were placed in front of the central field. An increase in luminance of the background was effected by adding the luminance of one projector to that of the other. A decrease was effected by having the background illuminated by both of the projectors, occluding one of the projections, and thereby subtracting its luminance from the total. A shutter mounted in front of the projector providing the luminance for the surround permitted an increase or decrease in the prevailing luminance simultaneous with that of the central field. Neutral density filters and small variations in lamp voltage controlled the luminances of the fields. Light from the field projectors was presented and cut off by shutter vanes mounted on rotary solenoids placed in front of them. Because there was a lower limit to the luminance provided by the surround projector, it was not always possible to match the luminance of the central field in all cases. The test letter was seen by reflection from a pellicle beam splitter placed between the central adapting field and the observer.

The experimental procedure consisted of the following: (1) A determination of the thresholds in both the transient and steady-state conditions was made in each experimental session. The steady-state determination was made after the subject had completely adapted to the new prevailing luminance level, and provided a base line for change in performance; (2) Contrast threshold determinations were made for the increases and decreases in luminance levels shown in Figs. 3 and 4. Fig. 3 shows the small luminance level changes studied in the first study and Fig. 4 shows the wide range of changes and levels of B_1 investigated in the second study; (3) The test-letter flash was always presented 0.3 sec. after the moment of transition in this series of experiments; (4) In these experiments, a test letter subtending a visual angle of 12 minutes at the eye was flash illuminated for 73 msec.; (5) Subjects adapted to the prevailing luminance level B_1 for 5 to 10 min., and the repeating cycle of change to the new level B_2, the test letter, and the return to the original prevailing level B_1 after 600 msec. at B_2 was started. The cycle was repeated every 15 sec.; (6) The subject was instructed to press the key corresponding to one of 8 Sloan-Snellen letters (C, H, K, N, R, S, V, or Z) he believed he had been presented; (7) The correctness of the response determined automatically whether or not the next test letter would be brighter or dimmer. A bell would also ring informing the subject when he had made a correct response. Thus, the "up and down" psychophysical method was used together with the forced-choice technique and knowledge-of-results.

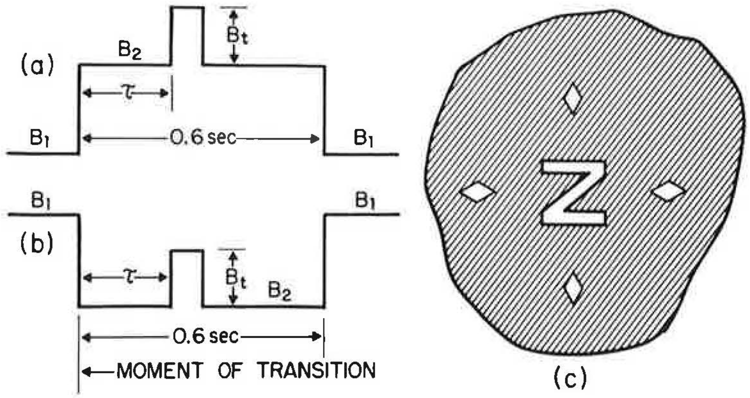
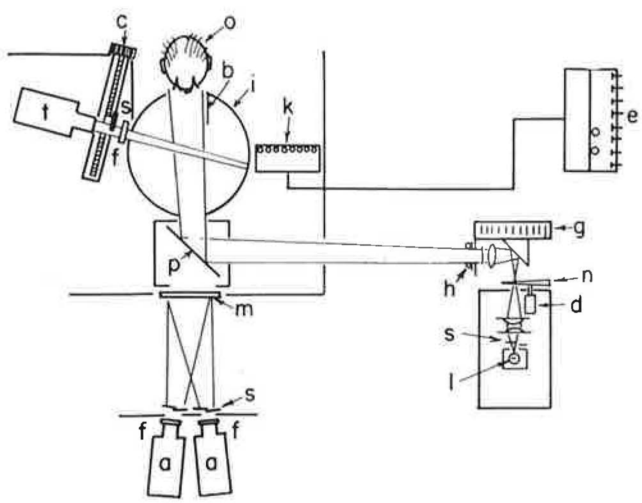


Figure 1. (a) Shown here is the schematic representation of the time sequence of stimulus presentations. The change from level B_1 to a higher level B_2 is illustrated. (b) The change from level B_1 to a lower level B_2 is shown here. (c) Appearance of the central adapting field during a test-letter flash for one of eight Sloan-Snellen letters used. Diamonds represent fixation lights. (Adapted from Boynton & Miller, 1963)



Schematic diagram of experimental apparatus. a—adapting field projectors b—baffle c—micro-dial and screw slide d—digital stepping motor e—experimenter's keys f—filters g—slide changer h—fixation lights i—integrating sphere k—keys for subject's response l—lamp for test projection system m—milk glass screen n—neutral density wedge o—observer p—pellicle beam-splitter s—shutters t—sphere projector.

Figure 2. Schematic diagram of the experimental apparatus used in the first two experiments described in the text. (From Boynton, Rinalducci, & Sternheim, 1969)

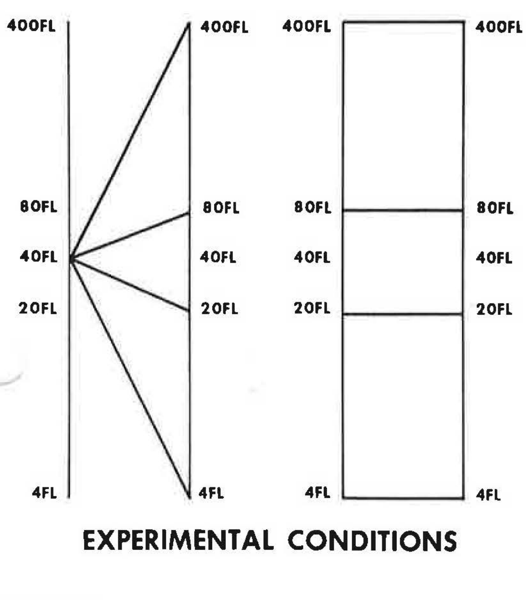


Figure 3. The relatively small luminance level changes investigated in the first study using a base of about 42 fL.

These methods were employed in order to provide for reliable and stable thresholds.

The value of tau used in these experiments was 300 msec. This value was chosen for several reasons (Boynton & Miller, 1963; Boynton, 1967). The threshold of the test-letter flash at this point in time is not very different from what it will be a second or so later. Secondly, by keeping tau at least this short we can return to the B_1 level after 600 msec. of B_2 with minimal disturbance of the B_1 level caused by the momentary change to B_2 plus the test-flash increment. In other words, we can avoid to some extent the effects of cumulative light adaptation and at the same time keep the experimental sessions as short as possible. Thirdly, it has been found that most people while reading or in everyday visual search make 3 or 4 fixations per second. Thus, 300 msec. appears to be a reasonable value for a single fixation under such conditions. In addition, it has been suggested that since the threshold is changing so rapidly during the first 150 msec. or so after the luminance change more reliable measurements might be made at a tau of 300 msec. Other values of tau have been used, however, both at Rochester and at Virginia. At the University of Virginia we have used tau values ranging from 100 msec. before the moment of transition to 400 msec after the transition as well as at 300 msec. after the change.

The results of these two studies are shown in Figs. 5 and 6, respectively. Fig. 5 shows log Phi as a function of log (B_2/B_1) fL or the ratio of change for a B_1 equal to about 40 fL. Plotted here are values for approximately 2-fold and 10-fold changes. In general, it may be seen that the small 2-fold changes produce little effect at least when the letter is presented 0.3 sec. after the moment of transition, and with the luminances used in this study. Taking into account data from other experiments as well as this one we may conclude that a sudden luminance change of about 10-fold in magnitude produces a performance loss of around 35 to 40%, evaluated in terms of the increase in test-letter flash contrast required to maintain threshold visibility. A 2-fold change produces a performance loss of only 10 to 15%. It might also be pointed out that in general when we take all the experiments into account, the visibility losses due to changes in the upward direction are about as great as those losses due to changes in the downward direction.

The second study included more subjects as well as extending the range of luminance levels used, and increasing the magnitude of the changes employed. Fig. 6 shows log Phi as a function of log (B_2/B_1) fL in which B_1 is varied. This Figure shows the effects of a certain factor of change using different values of the prevailing luminance level B_1 on log Phi. Both 5 and 6 show that there is an increase in log Phi (or a decrease in visibility) as a result of a sudden change in luminance level. The curves in Fig. 6 connect points for conditions where the starting level B_1 was the same, and of a value shown. In general, it would appear that both these experiments, and the second in particular, show log Phi as a function of the ratio of adaptational change especially within the range from 0.4 to 400 fL, and not as a function of the absolute adaptation level. This generalization breaks down, however, for many of the conditions where B_1 or B_2 = 4000 fL. The worst discrepancy occurs when B_1 = 4000 fL and B_2 = 40 fL. It can also be seen that when B_1 = 40 fL the upward changes produce larger values than the downward changes especially if it involves a B_2 = 4000 fL.

The most probable interpretation was put forward by Boynton et al (1969) who suggested that the very high values of log Phi obtained when B_1 = 4000 fL indicates that an additional additive process of photopigment bleaching has occurred. The effects of extensive bleaching are added on to the losses in visibility produced by masking. Losses in visibility at lower levels have been likened to a course variable-gain mechanism whose time constant will not permit a full adjustment within 0.3 sec., but which is nevertheless faster than the recovery from photopigment bleaching.

With regard to visibility losses from upward changes using a B_1 = 4000 fL, it is possible that a significant amount of bleaching may occur within as short a time as 0.3 sec. However, the inability to fixate and blinking may also contribute to the decrement in performance under this condition.

The condition employing the 4000 fL level for B_1 and B_2 would be analogous to the situation of entering or exiting a dark tunnel from or to a bright sunlit environment. The direction of the sun's rays and the reflection of surfaces within the visual field at the entrance and exit of the tunnel would of course be important in determining the luminance level change and resulting loss in visibility.

A third experiment of the same general nature as the two described above has recently been conducted at the University of Virginia. It involved low luminance levels similar to those that might be encountered in nighttime driving situations. Such situations often involve luminance levels provided by driving with headlights, fixed roadway lighting systems,

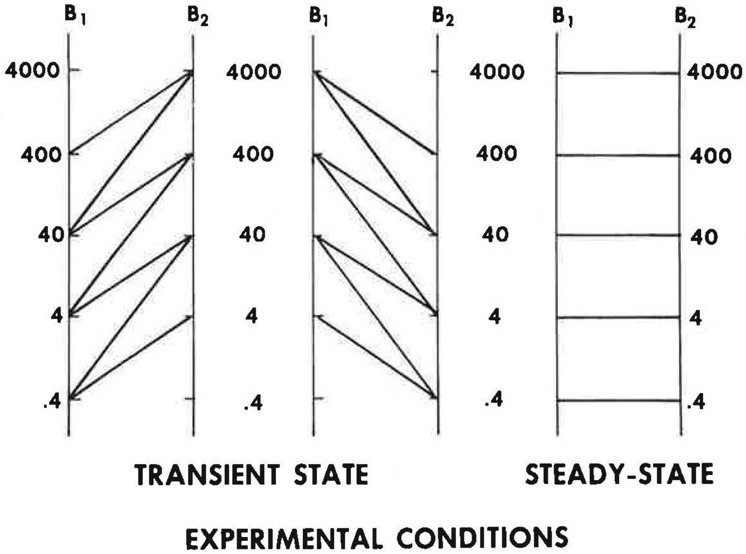


Figure 4. The relatively large luminance level changes and a wide range of levels of B_1 investigated in the second study.

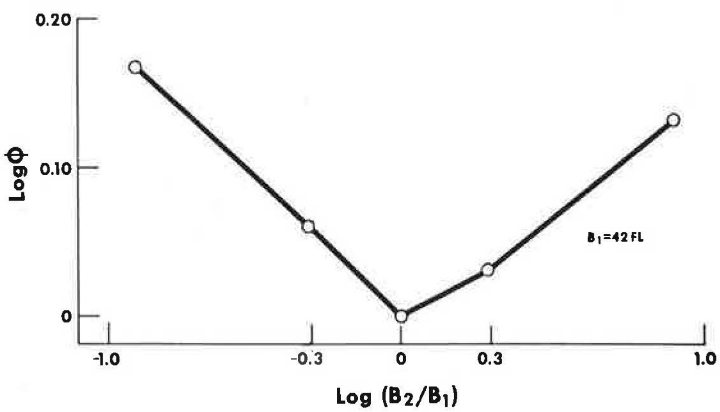


Figure 5. The results of the first experiment showing log Phi as a function of log (B_2/B_1) for a B_1 of 42 fL. (From Boynton et al, 1969, and Rinalducci, 1964)

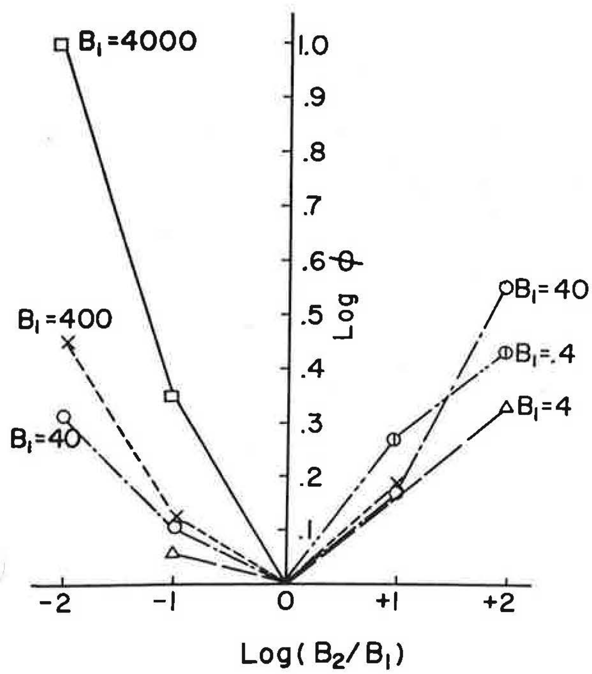


Figure 6. The results of the second experiment showing log Phi as a function of log (B_2/B_1) for various levels of B_1. (From Boynton et al, 1969 and Rinalducci, 1964)

or available ambient light. As applied to tunnel lighting, the luminance levels employed in this experiment would simulate the condition in which a motorist would enter a dimly illuminated tunnel from an even darker access road or would exit a dimly lit tunnel on to a more dimly illuminated highway. The conditions of this study would also simulate the situation in which the night driver glances from the highway illuminated only by his own headlights to the essentially unlighted shoulder of the road or vice versa.

A new apparatus to measure visibility losses under transitional adaptation was completed and calibrated at the University of Virginia. The apparatus is shown in Fig. 7. It can be seen that in most respects it is similar to that used in the two previous experiments. However, no provision for control of surround illumination was made in this system. This apparatus is essentially a free-viewing system with an adapting field provided by a flashed opal glass plate. The luminance changes of the adapting field were also controlled by programming the opening and closing of shutters placed in front of two projectors as in previous investigations.

In this study, the pre-adapting luminance, B_1, was always 0.02 fL (roughly equivalent to ambient light provided by the moon). The new prevailing luminance level, was either 0.0002, 0.002, 0.2, or 2.0 fL providing for 10- and 100-fold or 1 and 2 log-unit decreases or increases. In all, there were four transient conditions and five steady-state conditions. The latter included 0.0002, 0.002, 0.02, 0.2, and 2.0 fL.

The test-letter flashes were presented at twelve values of tau which were -100, -50, -10, 0, +10, +25, +50, +100, +200, +300, +400 msec. Negative tau values refer to test-letter presentation before the adapting-field change, positive values to presentation after change, and a zero value to presentation simultaneous with the change. The duration of the luminance level change, whether upwards or downwards remained at 0.6 sec. Only one test-letter size subtending 10.6 minutes of arc at the eye was used, and it was presented for 50 msec. Ten subjects were used in this investigation. They were required to adapt to the low prevailing luminance levels for 7 to 10 min., and then the repeating cycle of change from B_1 to the new level B_2, the test-letter flash (presented before, during, or after the moment of transition), and a return to the original prevailing level was initiated. Fifteen seconds elapsed between each repeating cycle in order to avoid adaptation to the new prevailing level. A warning signal was presented about 2 sec. before the moment of transition.

The same experimental procedures (the "up-and-down" psychophysical method, forced-choice technique, and knowledge-of-results) were employed in this study as in previous investigations. An Iconix, Inc. solid-state timing system programmed the presentation of the stimuli.

The results of this investigation are shown in Fig. 8 for all four transient-state conditions investigated. The graph shows log Phi as a function of log (B_2/B_1) fL for a tau of 300 msec. The values obtained in terms of log Phi or log B_t' (test-flash luminance) for the other values of tau are not shown here. In Fig. 8 we can see that roughly equivalent decrements in visibility are obtained for the same ratio of change in most cases. The largest loss in visibility was produced by the 2 log-unit increase in luminance level. This Figure also shows that the loss in visibility for the 1 and 2 log-unit upward changes and the 1 log-unit downward change compare favorably with the data obtained by Boynton et al (1969) using a B_1 of 4 fL and a B_1 of 40 fL for the same size changes in luminance level. There is, however, no further losses in visibility beyond the 1 log-unit downward change. As a result, the data for the downward changes do not entirely conform to the generalization that the ratio of change is the prime determinant of visibility loss. We might attribute this departure to the fact that we are dealing with luminances in the mesopic range of sensitivity. One explanation already alluded to for the exaggerated heightening of thresholds seen in transitional adaptation is that the change in luminance gives rise to a burst of activity in the visual system, and this sudden burst of neural activity essentially overwhelms or "masks" activity resulting from a signal superimposed on this change. At very low luminances, however, the visual photoreceptors require a certain minimum quantum change in the amount of light falling on them to produce a differential discharge. The photopic or cone receptors located primarily in the region of the fovea are probably being stimulated under the present experimental conditions. The fovea is that region of the retina where the retinal image of a fixated object falls. The differences in the number of quanta of light between 0.02 fL and 0.0002 fL may not be sufficient to occasion an "off" or burst of neural activity large enough to mask the signal any more effectively than a luminance change from 0.02 fL to 0.002 fL. Thus, visibility loss for a given ratio of change not only appears to have an upper limit of 400 fL, but there may also be a lower limit of 0.002 fL.

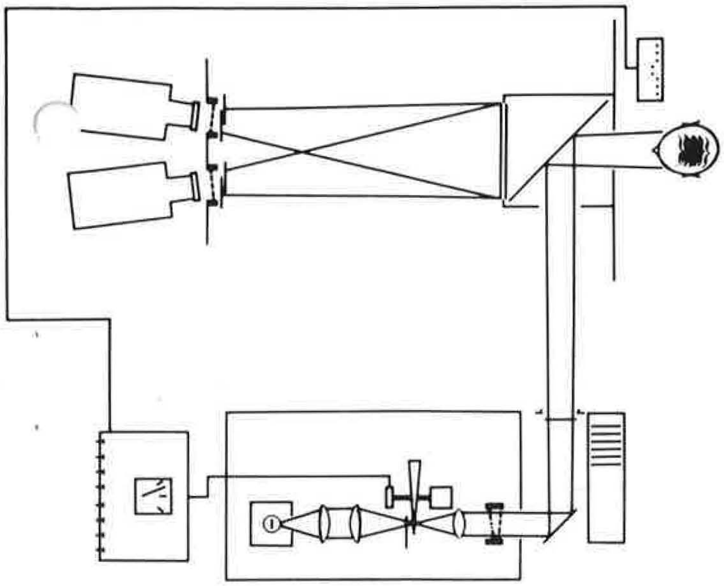


Figure 7. Schematic diagram of experimental apparatus used in the third study described in the text.

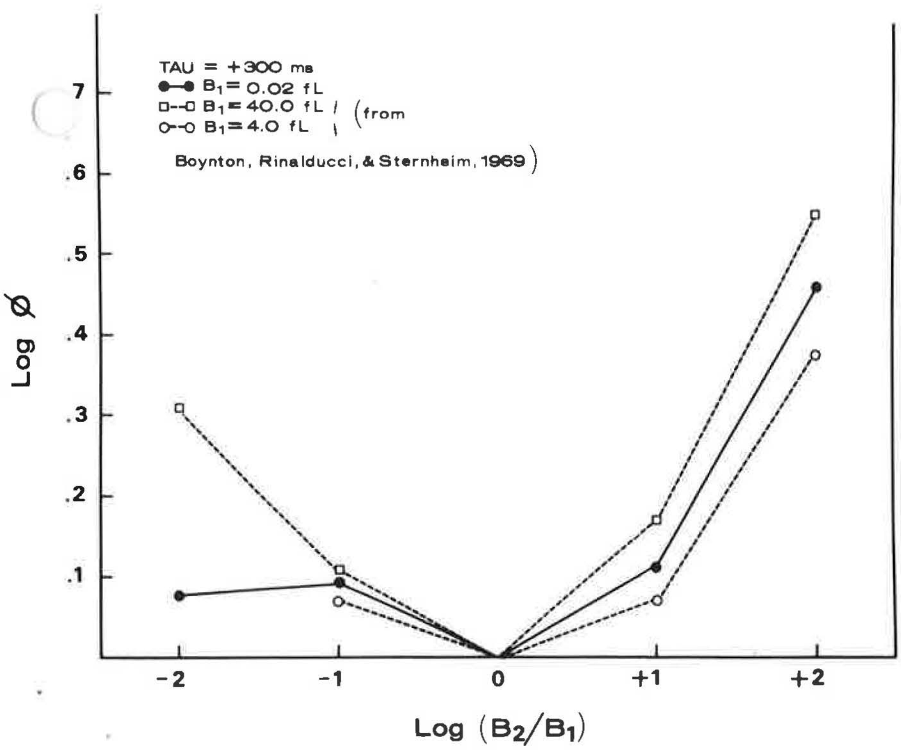


Figure 8. The results of the third experiment showing log Phi as a function of log (B_2/B_1) for a B_1 of 0.02 fL, and compared to the data of Boynton et al, 1969.

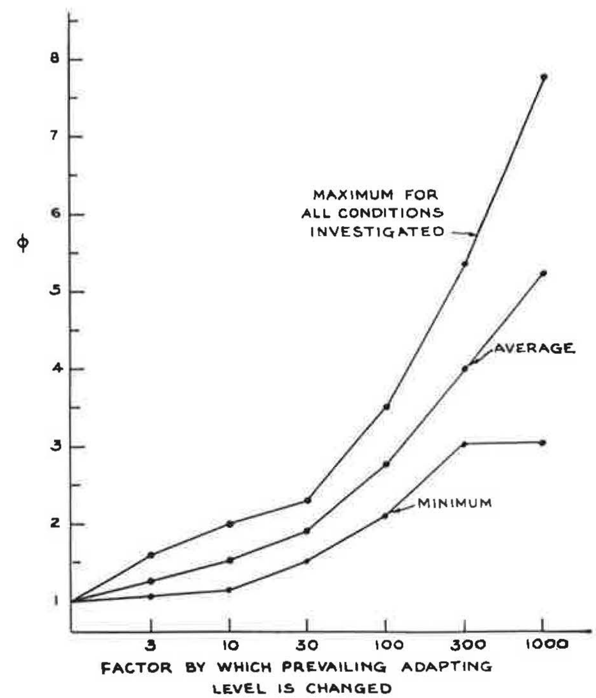


Figure 9. Phi is shown as a function of the factor of change from one luminance level to another. (From Boynton & Miller, 1963)

Fig. 9 shows the value of Phi as a function of the factor by which the prevailing luminance level is changed. These values are based on a number of experiments by Boynton and his associates (Boynton & Miller, 1963; Boynton, Rinalducci, & Sternheim, 1969). It might be pointed out that for the studies in which the B_1 = 4000 fL and B_2 = 40 fL the value of Phi was so great as to be off the graph, again illustrating the deleterious effects of high luminance levels. The results from the study involving low absolute luminance levels (except that value for the 100-fold decrease) would fall well within the envelope of the values shown in this Figure. The information presented here might be used for general illuminating engineering design applications. In terms of tunnel lighting situations it is envisioned that these data could be used to provide more gradual or smaller luminance changes at any one time in the design of lighting systems so as not to cause the motorist excessive loss of visibility.

REFERENCES

Boynton, R. M. Visibility losses caused by sudden luminance changes. Proceedings of the C. I. E., Washington, D. C., 1967.

Boynton, R. M., Corwin, T. R., & Sternheim, C. Visibility losses produced by flash adaptation. Illuminating Engineering, 1970, 65, 259-266.

Boynton, R. M., & Kandel, G. On responses in the human visual system as a function of adaptation level. Journal of the Optical Society of America, 1957, 47, 255-286.

Boynton, R. M., & Miller, Norma D. Visual performance under conditions of transient adaptation. Illuminating Engineering, 1963, 58, 541-550.

Boynton, R. M., Rinalducci, E. J., & Sternheim, C. Visibility losses produced by transient adaptational changes in the range from 0.4 to 4000 Footlamberts. Illuminating Engineering, 1969, 64, 217-227.

Rinalducci, E. J. Visibility as a function of sudden changes in luminance level. Paper read at Eastern Psychological Association, Philadelphia, April, 1964.