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Title: Effects of Transient Adaptation to Law

ADMINISTRATIVE DATA
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John E. Kaufman
Research Administration
Illuminating Engineering Research Institute
345 East 47th Street
New York, New York 10017

2) Sponsor Admin/Contractual Matters:

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See Attached Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget.

Equipment: Title vests with sponsor.

Comments:
Related to earlier research done under Project No. 642-632/Rinaducci. However, this one is to be considered new, not a modification.

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Project No. G-42-639

Includes Subproject No.(s)

Project Director(s) Dr. Edward J. Rinalducci

Sponsor Illuminating Engineering Research Institute

Title Effects of transient adaptation at low luminances

Effective Completion Date: 11/1/82

Grant/Contract Closeout Action: Remaining:

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Continues Project No. G-42-632

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ORM OCA 69.285
Non-Uniformities in transient Adaptation
Unrestricted Background Fields.

Edward J. Rinalducci
and
Rhea T. Eskew, Jr.

School of Psychology
Georgia Institute of Technology
Atlanta, GA 30332

Douglas A. Hardwick
Department of Psychology
Illinois State University
Normal, IL 61761

Johnathan Walker
Psychology Department
King College
Bristol, TN 37620
Visual adaptation is the process in which the sensitivity of the visual system adjusts to changes in luminance level over time. Some of these adjustments in sensitivity occur within a few hundred milliseconds, while others take as long as an hour to be completed. Research on transient adaptation is concerned with the rapid changes, which are thought to be primarily neural in nature.

When the eye is presented with a sudden increase or decrease in the prevailing level of illumination, a transient burst of neural activity occurs in the retina which is relayed along visual pathways, signalling the change. If an observer is asked to perform a visual task at this time, such as identification of a test letter, he or she will require greater contrast between the letter and the background than would have been required if the prevailing level of illumination had not changed. This is because the visual system is busy processing information related to the change in luminance level. Thus, the neural activity produced by the change masks the test letter. The greater the change in luminance level, the greater the amount of additional contrast which will be required to recognize the test letter. Eventually, the activity produced by the sudden luminance change subsides and the visual system reaches a steady state of complete adaptation.

The subtle nature of transient adaptation makes it important to first understand the basic phenomena associated with it by studying it in the laboratory in its simplest form. A number of such studies have been carried out, many under the auspices of the IERI. In particular, a series of studies performed by R.M. Boynton and his associates has developed the procedures and terminology used in the study of transient adaptation. These experiments elucidated the losses in visibility produced by sudden changes in luminance in the range of light levels associated with normal interior lighting; the current series of studies focuses on lower light levels, such as those associated with night driving. Because sudden changes in illumination levels are common in night driving, and because the visual losses brought about by such changes can have serious consequences, understanding transient adaptation as it relates to night driving is particularly important.

Several laboratory procedures have been used to investigate transient adaptation. In one of these, a target to be identified, such as a test letter, is presented at a particular time relative to the change in luminance level. The observer sees the letter superimposed upon the changing background. The interval between the beginning of the change from one background luminance \( B_1 \) to another \( B_2 \) and the onset of the test letter is designated by the Greek letter tau (\( \tau \)). This procedure is shown schematically in Fig. 1. An increase in luminance is shown in Fig. 1a and a decrease in Fig. 1b.

While the four experiments reported here followed this general procedure, there was one important difference. In the earlier studies, the background field was a uniform surface, which simply increased or decreased in luminance as the change from \( B_1 \) to \( B_2 \) was made. In the current research, the change in luminance was effected by presenting or removing one or more bright non-uniformities on an otherwise uniform, dimmer background. While the use of uniform fields was important in the earlier research in order to under-
stand the basic processes of transient adaptation, uniform fields of view are not common in our everyday visual environment; practical applications of research on transient adaptation require that we understand how non-uniform fields affect transient adaptation.

The results of previous studies have usually been interpreted in terms of the ratio of the contrast threshold of the target (e.g., a letter) in the transient state of adaptation to the contrast threshold of the target under steady-state or completely adapted conditions. Contrast threshold is defined as the luminance required for the target to be just recognizable divided by the luminance of the background against which it appears. Let $B_t$ represent the threshold luminance of the object when presented under transient conditions as shown in Fig. 1. Let $B_s$ represent the threshold luminance of the target when presented under fully-adapted or steady-state conditions (i.e., when there is no change in prevailing luminance). In all the experiments described here, the target was a letter presented against level $B_2$, in both transient and steady state conditions. When the contrast threshold for a test letter presented against a changing background is divided by the contrast threshold for a test letter presented against a steady background, the resulting ratio, symbolized by the Greek letter phi ($\phi$), provides an index of visibility loss.

\[
\phi = \frac{B_t/B_2}{B_s/B_2}
\]  

(1)

Where $B_t/B_2 = \text{contrast threshold of letter presented }\tau\text{ seconds following the change from }B_1\text{ to }B_2$, and $B_s/B_2 = \text{contrast threshold of the letter presented against the steady background }B_2$. This reduces to the dimensionless ratio

\[
\phi = \frac{B_t}{B_s}
\]  

(2)

where $B_t = \text{absolute threshold of letter presented during transient adaptation}$ and $B_s = \text{absolute threshold of letter presented during steady state}$.

The phi coefficient thus provides a convenient index of visibility loss. If, for example, ten times as much light is required to recognize a letter just after a change in prevailing luminance, relative to the amount of light required with no change in luminance, the value of the phi coefficient would be 10. Since \(\log \phi\) is usually the most convenient measure of visibility loss, the reported value would be 1.0 in this case.

**Apparatus**

Fig. 2 shows the apparatus used in the present investigation. It is a free-viewing system, very similar to the one employed by Rinalducci and Beare \(^7\)\(^9\). The subject looked through a beam-combining pellical at a large field of high-contrast back-projection screen. This field measured 54 x 66 degrees for all experiments, except for Experiment I and for one condition of Experiment IV, in both of which it measured 13 x 13 degrees. The subject's head was positioned by a chin and forehead rest. The background field was illuminated by two Leitz 250-watt slide projectors. An increase in luminance as effected by adding the luminance of one...
Light from the field projectors was controlled by shutter vanes mounted on rotary solenoids placed in front of them. The brightness of each projector was controlled by placing neutral density filters in their path; fine regulation was achieved by means of small variations in lamp voltage.

Non-uniformities were presented by means of slides placed in the gate of one of the two projectors. These were high-contrast negatives on Lithographic film, made from photographs of the desired non-uniformity. For transient conditions, the non-uniformity slide was placed in the projector behind the solenoid which was activated at the moment of transition. Thus, for upward changes the non-uniformity suddenly appeared against a dimmer, uniform field, while for downward changes the non-uniformity suddenly disappeared, leaving the dimmer, uniform field. In the gate of the other projector, a "compensating slide" was placed; this was simply a negative of a slide taken of the uniform background field, and when placed in the gate of the projector made the distribution of light more uniform across the background field.

The test letters were slides of eight equally-discriminable Sloan-Shellen letters (C, H, K, N, R, S, V, and Z) which were mounted in an automatic slide changer. These letters consisted of photographic negatives prepared on Kodalith high-contrast film. A plate carrying a diamond-shaped array of fixation points was mounted in the pellicle box at the same optical distance from the observer's eyes as the background field. The fixation points defined the location at which the letter would appear and allowed the subject to accommodate his eyes to the proper distance. A test-letter target as it would appear to an observer, superimposed on a background field within the array of fixation lights, is shown in part c of Fig. 1. The test letters subtended 10.6 minutes in all experiments reported here. The letters were transilluminated by a 108-watt microilluminator lamp having a horizontal tungsten ribbon filament. The luminance was regulated via neutral density filters, with fine adjustments made by means of a circular neutral-density wedge which was positioned by a bi-directional stepping motor. The shaft of the wedge was attached to a linear potentiometer, thus allowing the experimenter to read the wedge position on a remote voltmeter. Another rotary solenoid controlled the presentation of the test flashes, which were always 50 ms in duration.

The optics of the test channel projected a beam of light through the test letter so that it appeared in focus in the plane of the observer's eyes. Thus, the subject viewed binocularly the transilluminated background screen and saw by reflection from the pellicle beam splitter a flash-illuminated test letter centered within four fixation points.

An Iconix digital timing system controlled the sequence of background luminance changes, the presentation of a warning signal before each trial, test letter presentation, and the changing of the test letter slides.
Calibration

Luminances of the background field and the test letter-field were measured at the fixation point from the observer's eye position. Luminance measurements were made with a Gamma model 500 telephotometer. Densitometric measurements of all neutral density filters and wedges were also determined with this instrument. All lamps were continuously monitored by selenium-cell output and microammeters.

Time calibrations were performed with an EG&G "Lite Mike" and a Tektronix oscilloscope. The shutter rise time of the background field was determined to be approximately 18 ms, and the fall time was about 10 ms. Shutter rise and fall times for the test flash were about 10 ms. The duration of the test flash and B2 luminance presentation were determined by the same methods.

Procedure

The procedures employed in these experiments were quite similar to those used by Rinalducci and Beare. The prevailing luminance level B1 (the background luminance), measured at fixation, would either be increased or decreased by 1- or 2-log units (10 or 100 x) to a second luminance B2, except in Experiment II in which the change was increased to a 500-fold (2.7-log unit) change. B2 luminance was maintained for 1 second in the transient conditions for all four experiments reported here, and tau was always 300 ms. This value of tau was used for three reasons. First, it facilitates comparison with earlier work, much of which used this value. Second, it is a reasonable estimate of the length of a single fixation by a person in many visual tasks. Third and most important, at 300 ms after transition a person's visual sensitivity is not changing as rapidly as it is prior to that time, and thus a tau of 300 ms provides a good estimate of the effects of transient adaptation over a full second or so after the change.

In each experimental session the subject was first allowed to adapt to level B1 for five minutes. Then a 15-second cycle began in which the background changed from luminance B1 to luminance B2, by either presenting or removing the non-uniformity, for 1 sec, which was followed by 14 sec of level B1. The long recycle time, combined with the brief duration of exposure to level B2, ensured that the observer would be fully adapted to B1 at the moment of transition to B2. Two seconds before transition, or two seconds before presentation of the test letter under steady-state conditions, a warning buzzer sounded. The subject's task was to depress a key corresponding to the letter he believed had been presented. If the subject pressed the correct key in response to the letter a bell rang and the stepping motor moved the wedge about 0.1 log unit in the direction of increased density, thus causing the flash on the succeeding trial to be dimmer. If the response was incorrect, the bell did not ring, and the wedge was turned in the direction of decreasing density, thus making the next flash brighter. The psychophysical method used was thus the "up-and-down" or staircase method, combined with forced-choice responding and knowledge of results.

Thirty trials were run to determine each threshold. Threshold was defined as that luminance at which the letters were correctly identified 50 percent of the time, as determined by linear regression of percent correct on luminance. In each experimental session, a single random order of the test letters was used. In most cases, three thresholds (the transient and the two steady-state thresholds) were determined in each
session, in an unsystematic order to avoid bias. However, occasionally time limitations or subject fatigue required the use of a steady-state threshold determined on a different day from the transient one.

**EXPERIMENT I**

**Design.** The first study was concerned with visibility loss due to transient adaptation as a function of the area of a non-uniformity. The background field was 13 x 13 deg. The non-uniformity was a single square, superimposed over and centered on the fixation points. The width of the square was varied from 0.5 to 4 degrees. Fig. 3 shows the stimulus configuration, in which one of the square patches (B, C, D, or E) was superimposed on the background (A). Only one square was used in any given session. A test letter, V, is shown centered within a square patch. In the lower right-hand corner a schematic representation of the luminance change is shown. For downward changes, the bright patch was superimposed on the dim background for a combined luminance of 20 fl at fixation. At the moment of transition the patch was removed and the luminance dropped by a factor of 100 (-2 log unit change) to 0.2 fl. For the upward change the 0.2 fl background was presented until transition, at which time the 20 fl square appeared for 1 sec. Four subjects were used in this study.

**RESULTS**

Insert Figure 3 about here.

**EXPERIMENT II**

**Design.** While the first experiment varied the size of the non-uniformity, the second experiment varied the size of the background field against which it was presented. The non-uniformity was a 4 degree square patch, presented at 20 fl. The background field measured 54 x 66 degrees; its luminance was 0.2 fl. Thus, presenting the square at the moment of transition resulted in a downward 100-fold (-2 log unit) change. The obtained results were compared to those of Experiment I in which the 4 degree patch was presented against the 13 x 13 degree background field. In addition, visibility losses were determined for the condition in which the entire 54 x 66 degree field changed upwards or downwards by a factor of 100 in luminance. Two observers were tested using the 54 x 66 degree field. Their results were compared with the four observers from Experiment I.

**RESULTS**

Insert Figure 4 about here.

Results. The results are presented in Fig. 5. It can be seen that the 4 degree patch had a less detrimental effect on visibility when presented on the 54 x 66 degree field than when presented against the 13 x 13 degree field.
However, the largest losses were obtained when the entire field changed. Possible explanations of this effect will be described in the Discussion.

**EXPERIMENT III**

Design. The purpose of the third study was to determine the effect of varying the number of non-uniformities on visibility loss. The non-uniformities used in this study were small squares, centered on the fixation points. Four configurations were used, as is shown in Fig. 6: the individual squares in part a of the Figure were 1.79 deg on a side, while the individual squares in part b of the figure were 1.33 deg on a side, the purpose being to keep the area of the array a constant 16 square degrees.

**EXPERIMENT IV**

Design. A variable which would be expected to change the effect of a non-uniformity on transient adaptation is the distance of the non-uniformity from the direction of gaze. In this experiment the distance of four 2 x 2 degree square patches from line-of-sight was 1, 2, or 5 degrees. This arrangement is depicted schematically in Fig. 8.

Results. Log phi and phi are plotted against the separation of the squares from fixation in Fig. 9. Since phi coefficient of less than 1.0 indicates improved visibility under transient relative to steady-state conditions, it appears that the 10-fold upward change (symbolized by the filled circles) produced an improvement in visual sensitivity, particularly for the 2 deg separation. The downward changes did not differ meaningfully from 1.0, indicating these had no effect on visibility. The 100-fold upward change, indicated by the unfilled circles in Fig. 9, shows a slight loss in sensitivity for the 2 deg separation.

As these results were unexpected, the study was repeated with a larger luminance change. The luminances used were 0.2 up to 100 fl, and 100 down to 0.2 fl (i.e., a log change of 2.7). These levels are shown schematically in the inset of Fig. 10. Fig. 10 plots log phi and phi against degree separation. At this higher luminance change a clear and
consistent effect of separation from line-of-sight is seen. The closer the squares were to fixation, the larger the visibility loss. The decline in visibility loss with increasing distance from fixation was more rapid for the upward than the downward change in luminance.

GENERAL DISCUSSION

The four studies reported here demonstrate that losses in visual sensitivity can be brought about by the abrupt presentation or removal of one or more bright patches against a dim background. Four of the most basic parameters of this phenomenon have been explored: the area of the non-uniformity, the area of the background field, the number of non-uniformities, and the distance of non-uniformities from fixation. All of these parameters are relevant to many highway lighting and other practical situations. For example, one may regard the luminaires above a roadway or a patch of light on a road-surface as a non-uniformity. It is a matter of practical interest to know whether one bright luminaire will cause more or less loss in visibility due to transient adaptation than several dimmer luminaires, and how this might interact with angle of the luminaires from fixation.

Experiment I demonstrated that the larger the square superimposed on a background field, the larger the loss in visibility under transient conditions as measured by the phi coefficient. The slope relating non-uniformity area to phi was slightly greater for the upward than the downward change. Experiment II varied the size of the background field against which non-uniformities were presented. The four degree square non-uniformity was presented against a 13 x 13 degree or a 54 x 66 degree field. The use of the smaller background field led to more visibility loss for the 4 degree non-uniformity. However, an even greater loss of visibility occurred when the entire 54 x 66 degree field changed in luminance (i.e., when there was no non-uniformity), as is shown in Fig. 5. The most obvious interpretation of this finding is that it is the proportion of the field which changes, rather than the absolute area of the change, which controls visibility loss. Fig. 11 re-plots these same data to demonstrate this finding. Log phi is linearly related to the log proportion of the area which shifted in luminance at transition. Note also that the slope is greater for the upward than the downward change. Fig. 12 re-plots these same data with proportion of total intensity (area times luminance) change on the abcissa rather than proportion of area change. Note that the curve is negatively accelerated towards both extremes. This is likely due to the larger total intensity changes being accomplished by areas further from fixation.

The difference in slopes between the upward and downward luminance changes seen in Fig. 11, and possibly Fig. 4, is of some interest. There are at least two factors which may have contributed to this difference between slopes.

First, as Rinalducci and Beare 9 have discussed, Weber's law breaks down at very low luminances approaching threshold. The burst of neural activity caused by abrupt luminance changes may be the same for 1- or 2-log-unit decrements, because of this breakdown in Weber's law.
The second factor which could contribute to the slope being less in the downward changes results from the asymmetric way luminance changes were effected in the present study: the bright non-uniformity was in view simultaneously with the target letter only in the upward conditions, while in the downward conditions the letter was seen against a dimmer uniform field. The sorts of non-uniformities used here are potential sources of disability glare when presented simultaneously with the target; clearly there can be no veiling luminance from a source which has just been removed, so the potential glare cannot be a factor in the downward luminance changes. However, the phi coefficient is defined as the ratio of the transient threshold to the steady-state threshold, and the glare is present in both cases and presumably would affect both. Thus, we may be dealing with an effect of glare which is unique to a situation involving rapid changes in luminance level. The possible existence of such a "transient disability glare" factor warrants further investigation.

Experiment III demonstrated that the number of patches had no effect on phi, provided the total area of the patches remained constant. Experiment IV found little consistent effect of separation of non-uniformities from fixation except at high luminance ratios and small (less than 2 degree) separations, as shown in Fig. 10.

CONCLUSIONS

1. The effect of the area of a non-uniformity upon visibility loss in transient adaptation can only be determined with reference to the area of the background against which the non-uniformity is seen. Phi varies directly with the proportion of area of non-uniformity to area of background. This is likely an effect of the relative energy flux of the fields. The implication for highway design is that when large fields of view are involved, larger lighted areas near fixation may not cause great visibility losses. However, if the field of view is restricted (for instance by terrain or other surrounding features) then the same bright patch might have a profound effect on visibility under transient conditions.

2. The number of non-uniformities is not important, at least under the range of conditions investigated here. Thus, the decision whether to use one bright luminaire or several dimmer ones to illuminate a given area may be made on the basis of other considerations, such as cost, provided the areas involved are not critical with reference to item 1.

3. The results of Experiment IV imply that only non-uniformities very near fixation will cause much loss of visibility in transient adaptation. The design engineer would be well advised to avoid placing luminaires within 2 degrees of likely fixation positions, where possible.
REFERENCES


Figure 1. (a) Schematic representation of sequence of events in stimulus presentation. Transition from background luminance $B_1$ to a higher luminance $B_2$ is illustrated. At time interval ($\tau$) after the moment of transition a test letter of luminance $B_t$ is presented superimposed upon the background. (b) Same as (a) except transition is from $B_1$ to a lower $B_2$ luminance. (c) Stimulus configuration as seen by the subject. The diamonds are fixation points. (Figure adapted from Boynton and Miller, 1963).

Figure 2. Diagram of the apparatus. (a) Side view. (b) Top view. See text for explanation.

Figure 3. Stimulus conditions for Experiment I. Square A is the background field; one of the other squares (B - E) was the non-uniformity presented in any given session. The test letter (TF) subtended 10.6 min in all experiments. See text for additional explanation.

Figure 4. Log phi as a function of the width of the square non-uniformity from Experiment I. The right-hand ordinate scale allows direct (approximate) reading of phi.

Figure 5. Log phi as a function of the log ratio of luminance change for Experiment II. The circles represent the 4 deg square presented against the condition in which the whole 54 X 66 deg background changed in luminance (no non-uniformity). The triangles represent the 4 deg square presented against the 13 X 13 deg background field from Experiment I, presented for comparison.

Figure 6. The stimulus configurations for Experiment III. The individual squares on the left half of the figure measured 1.79 deg on a side, while those on the right half measured 1.33 deg.

Figure 7. Log phi as a function of the log ratio of luminance change for Experiment III.

Figure 8. The stimulus configuration for Experiment IV. The test letter Z is shown centered within the fixation points.

Figure 9. Log phi as a function of the separation of the squares from fixation: Experiment IV. The log luminance ratios are 2, 1, -1, and -2.

Figure 10. Log phi as a function of the separation of the squares from fixation for a larger luminance change: Experiment IV. The log luminance ratios are 2.7 and -2.7.

Figure 11. Data from Experiment II re-plotted to show log phi as a function of the log proportion of the area of the non-uniformity to the area of the background against which it was presented. The solid and dashed lines indicate upward and downward luminance changes, respectively. Other symbols are as in Figure 5.
Figure 12. Data from Experiment II re-plotted to show log phi as a function of the log change in total intensity, defined as the product of the area of the field or non-uniformity (A) and its luminance (B). Symbols are as in Figure 5.
MOMENT OF TRANSITION
A  Projector
B  Shutter
C  Screen
D  Windows
E  Pellicle
F  Mirror
G  Fixation points
A Projector
B Shutter
C Screen
D Windows
E Pellicle
F Mirror
G Fixation points
H Slide
I Mirror
SO SUBTENDS
A 13 X 13 DEG
B 4 X 4 DEG
C 2 X 2 DEG
D 1 X 1 DEG
E .5 X .5 DEG
TF 10.6 MIN SQ

B1 > B2

B1
B2

B1
B2
PHI AS F (AREA)  N = 4
X : B1 = 20.0  B2 = 0.2
0 : B1 = 0.2  B2 = 20.0
AREA STUDY

\[ \log \frac{B_2}{B_1} - 2 \quad \text{vs} \quad \log \frac{B_2}{B_1} 0.01 \]

\( (N = 2) \quad 4^\circ/54^\circ \times 66^\circ \)

\( (N = 4) \quad 4^\circ/13^\circ \times 13^\circ \)

Increased Contrast
1 and 5 squares
1 and 9 squares

STIMULUS CONFIGURATION
NUMBER STUDY
NUMBER STUDY

N=8

Con tras t

N-...

In cre a t

Log (3 2 /3 1 )-2
(B 2  6 1 ) 0.01

Increased Contrast
STIMULUS CONFIGURATION

INSIDE CORNERS OF FOUR SQUARES SEPARATED BY 1, 2, OR 5 DEG.
SEPARATION OF SQUARES (DEG)

N = 6

- 0.2 to 100 fL
- 100 to 0.2 fL

LOG PHI

PHI

0.40
0.30
0.20
0.10
0.00
-0.10
-0.20

2.51
2.00
1.58
1.00
1.26
0.79
0.63

1
2
5

0.10
0.00
-0.10
-0.20
AREA STUDY

\[ \log \left( \frac{B_2}{B_1} \right) = -2 \]
\[ \log \left( \frac{B_2}{B_1} \right) = +2 \]

- \( 4^\circ \times 4^\circ / 54^\circ \times 66^\circ \)
- \( 4^\circ \times 4^\circ / 13^\circ \times 13^\circ \)
- \( 54^\circ \times 66^\circ / 54^\circ \times 66^\circ \)

LOG PROPORTION OF BACKGROUND AREA CHANGE
Log change in total luminous intensity

\[
\log \left( \frac{B_2A_2}{B_1A_1} \right)
\]

Legend:
- 4° x 4° / 54° x 66°
- 4° x 4° / 13° x 13°
- 54° x 66° / 54° x 66°