# THE RELATION BETWEEN THE ADAPTATION TIME IN THE EYE AND THE RATE OF VARIATION IN THE LUMINANCE[1]

Akihito Nakamura

## Introduction

Up to the present time, it has been a purpose in the studies of dark adaptation to find a certain relation between the adaptation process in the darkness and the intensity, or the duration, of the pre-adapting light to which the eye has already adapted just before it is put in the darkness (see, for example, Hecht, Haig, & Chase, 1937; Wald & Clark, 1937; Mote & Riopelle, 1951). It was shown in these studies that as the intensity or duration of pre-adapting light increased, the early visivility in darkness decreased and the adaptation time, i. e., the time from the begining of darkness to the final dark adaptation, was longer.

As mentioned above, the adaptation time in darkness becomes longer as the intensity of the pre-adapting light increases. This means that the adaptation time becomes longer as the amount of variance of the intensity increases. The present paper was devoted primarily to a study of adaptation process, especially the adaptation time after a change from lightness to less lightness but not to darkness. Then an attempt was made to investigate the following two points:

(1) That if the intensity of light is subdued, the adaptation time will, or will not, make a difference by the intensity or pre-adapting light. If there is a difference, what is the degree of the difference?

(2) If Fechner's law can be applied to the mechanism of light sensation, the following formula may be presented:

$$R_1 = c \ \mathrm{Log} \ \frac{I_1}{I_0} \qquad R_2 = c \ \mathrm{Log} \ \frac{I_2}{I_0}$$

therefore

$$R_1 - R_2 = c \ \mathrm{Log} \ \frac{I_1}{I_2} \cdots\cdots\cdots (1)$$

where

$R_1$ : The states of light sensation adapted to the pre-adapting light.
$R_2$ : The states of light sensation to the adapting light.
$I_1$ : Intensity of pre-adapting light.
$I_2$ : Intensity of adapting light.
$I_0$ : Absolute threshold.
$c$ : Constant.

Now, it seems that the amount of variation of light sensation, $R_1 - R_2$, is proportioned to the adaptation time $T_A$,

then $R_1 - R_2 = a\, T_A$ (a is a constant)

[1]A part of the result of this experiment was presented at the congress of the Japanese Psychological Association, July 1968.

if $aT_A$ is put into the formula (1),

$$T_A = \frac{c}{a} \text{Log} \frac{I_1}{I_2} = K \text{ Log} \frac{I_2}{I_1} \cdots\cdots\cdots (2) \qquad (K \text{ is a constant})$$

If the ratio of the amount of variation in intensity to the intensity of pre-adapting light can be defined as the rate of variation in intensity, $V_R$, then

$$V_R = \frac{I_1 - I_2}{I_1} = 1 - \frac{I_2}{I_1}$$

therefore $\frac{I_2}{I_1} = 1 - V_R$, put into the formula (2)

$$T_A = K \text{ Log } (1 - V_R) \cdots\cdots\cdots (3)$$

This formula indicates that the adaptation time is proportional to Log $(1 - V_R)$, that is Log $\frac{I_2}{I_1}$, and that if the rates of variation are constant, the adaptation time will be always constant independently of $I_1$ or $I_2$. Verifying these relations is the second purpose of this study.

It seems that the adaptation time depends not only upon the intensity of the pre-adapting and the adapting light but also upon the methods in changing the intensity of light. There are two methods in changing from $I_1$ to $I_n$. One is an instantaneous change in the temporal aspects, $I_1 \rightarrow I_n$, the other is gradual, $I_1 \rightarrow I_2 \rightarrow \cdots\cdots I_{n-1} \rightarrow I_n$. Farthermore, there will be a slow changing and a fast one in the gradual methods. The adaptation time may differ in these methods of changing in light intensity. Although those matters mentioned above are not essential to the present study, they will be considered at the end of this paper, from the results of experiment, since they seem useful as a clue to studies in future.

## Methods

**Apparatus** The pre-adapting and the adapting light radiate from the projector A, and the test light from the projector B. These lights illuminate a screen, which is made of milk glass, and subjects observe the stimulus on the opposite side (see figure 1). Intensity of light is controled by using filters of photo film with various densities. An adaptation time is measured by electromotive stop watch, which begins to move as soon as an adapting light radiates, and stops immediately as a subject pushes the key.

**Stimulus** The pre-adapting and the adapting field are both a circular light with a diameter of 15° 50′ in visual angle, and the test field is also circular with 1° 20′. Their centers are in the same position. The intensities of pre-adapting light used are 0.82, 4, 16, 46, 218, 566, 870, and 1520 rlx, and the test light are 0.25, 0.82, 4, and 16 rlx.

**Procedure** After a dark adaptation during twenty minutes, the pre-adapting light was illuminated for two minutes to the subject's eye, after which immediately the adapting light and the test light were given at the same time. The left eye of

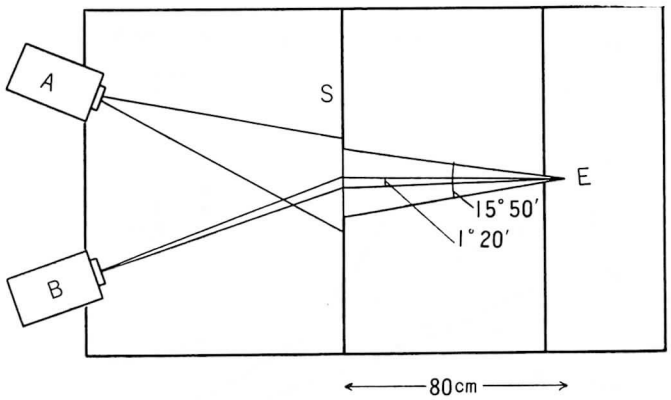



**Fig. 1** Apparatus. A : Projector for the pre-adapting and the adapting light. B : Projector for the test light. S : Scleen. E : Position of eye.

the subject was covered by an eye patch. Subject watched the center of the pre-adapting or the adapting light by the right eye. He was requested to push the response key as soon as possible, when he could recognize the test light. The time from the start of the adapting light to the pushing response was defined as the adaptation time. Before an experiment the subject had practiced the pushing response to the test light. The test light, which was used for the measurment of adaptation time, had previously been decided in the preliminary experiment in each case of each subject and each intensity of adapting light. The intensity of the test light gave a 100% frequency of seeing when the eye had been adapted to an adapting light, and the intensity was just above the difference threshold. Through this experiment, the procedure was adopted that the intensity of adapting light was brought down smaller that of the pre-adapting. The measurment of an adaptation time was done three times under every thirty different conditions. Four university students were used as subjects.

## Results

(1) The relation between the intensity of adapting light and the adaptation time.

Figure 2 shows the relation between the intensity of adapting light and the adaptation time in each case of every intensity of pre-adapting light. The plotted values of adaptation time are the averages of those obtained from four subjects. The horizontal axis in the graph is graduated in logarithmic scale. From figure 2 it will be seen that if the intensity of pre-adapting is constant the adaptation time increases as the intensity of adapting light decreases. While if the intensity of adapting is constant the adaptation time increases as the intensity of

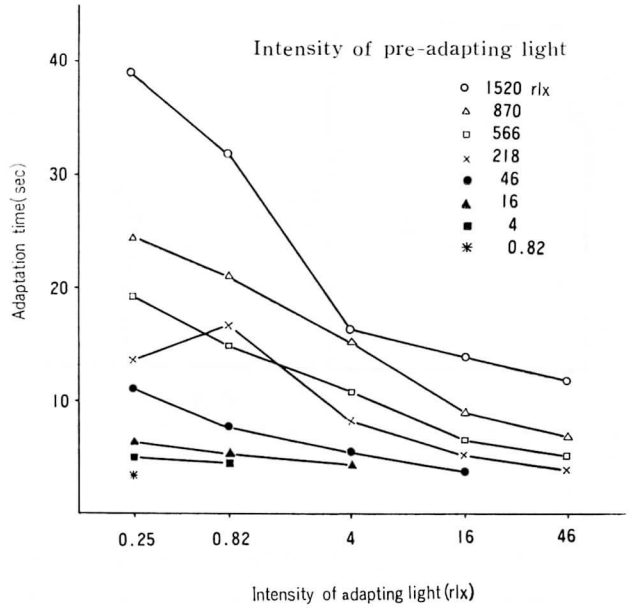



**Fig. 2** The relation between the intensity of adapting light and the adaptation time, in each case of the intensity of pre-adapting light.

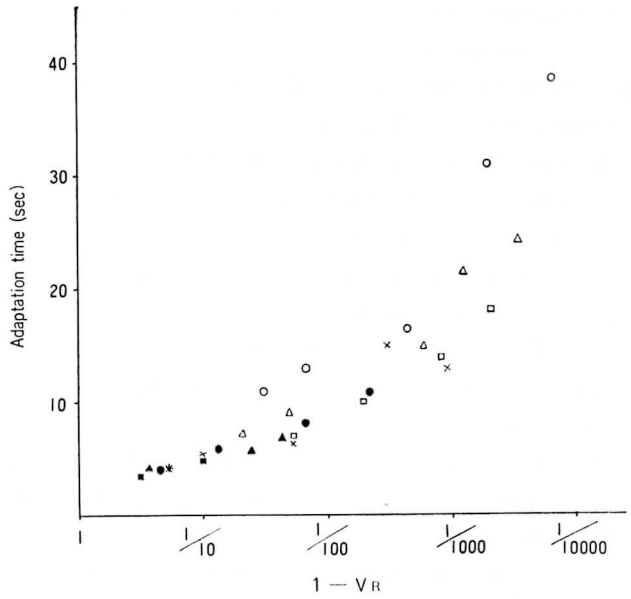
pre-adapting light decreases. From these results it may be concluded that if the intensity of pre-adapting or the adapting light is constant, the adaptation time increases as the amount of change in intensity increases. This is in agreement with the results obtained by Hecht and others in the condition of the shifting from a lightness to darkness. But the adaptation time does not depend on the absolute amount of change in intensity itself. For instance, the adaptation time in the change from 1520 to 46 rlx is shorter than that from 566 to 0.25 rlx, though the former is larger than the latter in the change of intensity of light. The adaptation time in the change from 1520 to 4 rlx and that from 566 to 0.82 rlx is about the same but the amount of change in intensity is noticeable in the former.

On the whole, the adaptation time measured in this experiment is relatively short. For instance, the eye can adapt entirely in forty seconds at most, even if the change of intensity is most striking, 1520 to 0.25 rlx, although the results of Hecht and others indicated that the adaptation time was over ten minutes, even in a small change of intensity, from 263 to 0 photon.

(2) The relation between the rate of valiation in intensity of light and the adaptation time.

Figure 3 shows the relation between the rate of variation in intensity and the adaptation time in the case of every intensity of pre-adapting light. The numbers given in holizontal axis are value of $\frac{I_2}{I_1}$, namely $1-V_R$. Therefore, the decrease

of this value means that the rate of variation of intensity increases. It will be seen from figure 3 that the adaptation time becomes longer as the rate of variation of intensity increases, and that when the rate of variation is less than 999/1000 the plotted points crowd near a straight line. But when the rate is over 999/1000 this tendency disappears, and even if the rate of variation is constant, the adaptation time becomes longer as the intensity of pre-adapting light increases. From these findings, it may be concluded that when the rate of variation of luminousity is under 999/1000 and if the rate of variation is constant, the adaptation time also comes to an equal value, independent of the intensity of pre-adapting or adapting light, and the formula (3) holds good approximately.




**Flg.** 3 The relation between the value of $1-V_R$ and adaptation time, in each case of the intensity of pre-adapting light.

## Discussion

The previous studies of dark adaptation, done mostly under the condition that the intensity of light illuminating the eye was shifted instantaneously from a lightness to darkness, have a close relation to the present study. In this study, the intensity of both pre-adapting and adapting is variable, while in the previous studies, only the intensity of pre-adapting light was variable and the intensity of

adapting was constant of zero. When the intensity of adapting is zero, it takes a subject about thirty minutes to adapt to the darkness; then if the values of adaptation time were plotted on figure 2 under a supposed condition of the adapting luminosity of zero, it would be seen that the adaptation time increases sharply as the intensity of adapting light comes up to the zero.

From the view point of the rate of variation, when the intensity of light does not change at all, in other words, when the intensity of pre-adapting is equal to that of adapting, the rate of variation becomes zero, and when the intensity of adapting is zero, the rate of variation is 1. After all, it is able to assert that the rate of variation in intensity ranges from zero to 1. Therefore, if the relation between the rate of variation in intensity, when the rate comes to 1, and the adaptation time were plotted in a figure, the adaptation time would be increased sharply and the differences of the adaptation time caused by the intensity of pre-adapting light would become clear.

Now, in respect to the formula (3), since the right side is logarithm the value of $1-V_R$ never comes to zero. Then, when $V_R$ is 1, that is, when the intensity of adapting light is zero, the formula does not hold. Moreover, it is supposed that the formula itself indicates from the first that if the rate of variation is 1 or near 1 it does not hold. If the rate of variation is zero, the adaptation time is zero ; therefore each curve plotted in figure 3 must pass the origin.

From figure 3 it will be seen that in a higher rate of variation the gradient of each curves becomes steep as the rate of variation increases. As the rate of variation is under 999/1000, this tendency is not clearly observable. But it is conceived that the tendency may be seen also in a lower rate of variation, and there are differences in the adaptation time caused by the intensity of pre-adapting, even if the rate of variation in intensity is constant. Further investigations will be necessary to solve these problems.

The problems of the change of luminosity in the adaptation of eye, taken up in this paper, can also be applied to the light adaptation process. Baker (1949) and many others made a study of light adaptation under the condition of the instantaneous shift from darkness to a lightness. For the problem of light adaptation further studies will be needed in the conditions of the shift from a lightness, not from darkness, to a higher degree of lightness. Baker, Doran, and Miller (1959) studied the early light adaptation in this condition, but they took on account of the adaptation time.

Attention may be drawn to the following matter. In this study an index to the measurment of the adaptation time was a simple reaction time, the time from the start of test light to the key reaction shown as soon as the subject saw the light. The adaptation time involves both the perceptual reaction time, from the start of test light to the "seen" reaction, and a motor reaction time, from the "seen" reaction

to the key reaction. What is necessary for this study is the perceptual reaction time. Therefore, the motor reaction time must be deducted from the simple reaction time. However, since it is well known that the simple reaction time to the light is 200 to 400 milli-seconds, the motor reaction time must be under this value. It is clear that the motor reaction time is considerably short compared with the simple reaction time (adaptation time) measured in this study. Then it will not be difficult to consider the adaptation time as the perceptual reaction time.

THE INSTANTANEOUS CHANGE AND THE GRADUAL CHANGE IN LUMINOSITY. The present study has taken up a question of the adaptation time in the eye under a condition of an instantaneously decreased intensity of light; from the results an attempt may be made to anticipate the adaptation time in the gradual decrease of the intensity.

There are various methods of shifting the intensity gradually from $I_1$ to $I_n$. First, as in figure 4, there are a method to shift step by step, and another to shift continuously. In the former method, it is necessary to decide the duration of light in each step; in the latter method, it is necessary to decide the gradient at each point. In the next place, the theoretical value of the time in shifting step by step is compared with that in shifting instantaneously. Suppose that the duration in each step is equal to the adaptation time in a step following another. When the adaptation time in the instantaneous shift from I*i* to I*j* is represented by T*i*-*j*, the duration in each step is represented by $T_{1-2}$, $T_{2-3}$, ·····$T_{(n-1)-n}$. Now let it be examined whether a difference is found between $T_{1-n}$ and $T_{1-2}+T_{2-3}+$·····$+T_{(n-1)-n}$ or not.

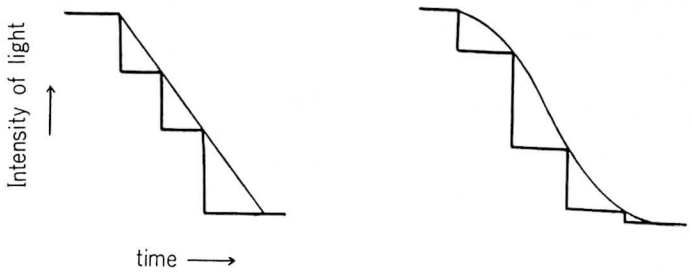



**Fig. 4** The methods of changing luminosity.

For instance, in the change from 1520, 870, 218, or 46 rlx to 0.25 rlx, as shown in figure 5, the value obtained of $T_{1520-0.25}$ was 39.6 seconds, while the theoretical adaptation time in the change in intensity by five steps should be 24.7 seconds, and that by three steps 20.3 seconds. Further the value of $T_{870-0.25}$ was 24.7 seconds, while the adaptation time by five steps should be 21.0 seconds, and that by three steps 16.6 seconds. From these facts it may be concluded that the adaptation time

by three steps is shorter than that in the instantaneous change or in the change of five steps. $T_{218-0.25}$ is 14.1 seconds, while the adaptation time by five steps is longer than 14.1 seconds, and that by three steps is slightly shorter. $T_{46-0.25}$ is 11.2 seconds, while the value by four steps is longer than 11.2 seconds; that by three steps is almost equal to this; and that by two steps is shorter. In the upper two in figure 5, there are a remarkable difference in the adaptation time between the instantaneous change and the change by steps. In each pre-adapting light, when the number of steps is a little too many, it happens that the adaptation time is longer than that in the instantaneous change. It is considered that since a motor reaction time is involved in every steps, its accumulation may be the cause of the increasing adaption time. But there is little possibility of this, because the total of each motor reaction time may be only one or two seconds.

As indicated above, it is supposed that the adaptation time in the gradual change of luminosity may be shorter than that in the instantaneous change, and if the speed of variation in luminosity is too fast, the adaptation time may be longer. As these are but a presupposition, further experiments on this problem are necessary.

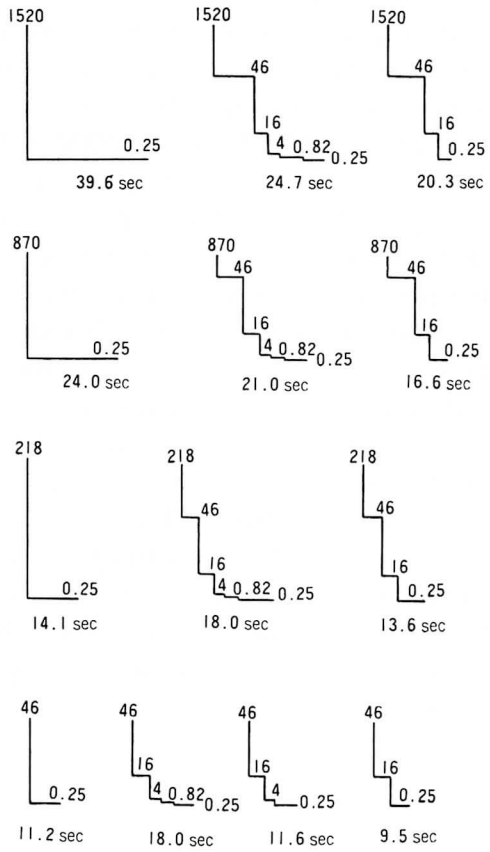



**Fig. 5** Adaptation time in the methods of changing luminosity. The values of adaptation time in the most left side are that obtained in this study, the others are theoretical value.

## Summary

This experiment was made to investigate the following two points : (1) That if the intensity of light is subdued, the adaption time in the eye will, or will not, make a difference by the intensity of pre-adapting light. If there is a difference, what is the degree of it? (2) When the ratio of the amount of variation in intensity to the intensity of pre-adapting light defined as the rate of variation in intensity, i. e. $V_R$, it was presupposed that the next formula would hold :

$T_A = K \text{ Log}(1 - V_R)$, where $T_A$ is the adaptation time, and K is a constant. The adaptation time after a change from a intensity of light (pre-adapting light) to less intensity (adapting light) was measured.

(1) The relation between the intensity of adapting light and the adaptation time was shown in figure 2. From these results it was concluded that if the intensity of pre-adapting or the adapting light is constant the adaptation time increases as the amount of change in intensity increases.

(2) The relation between the rate of variation in intensity and the adaptation time was shown in figure 3. From these findings, it was concluded that when the rate of variation of luminosity is under 999/1000 and the rate is constant, the adaptation time also comes to an equal value, and the above formula hold.

(3) From the results of experiment, an attempt was made to anticipate the adaptation time in the gradual decrease of the intensity. It was supposed that the adaptation time in the gradual changes of luminosity may be shorter than that in the instantaneous changes, and if the speed of variation in luminosity is too fast, the adaptation time may be longer.

## References

Baker, H. D. 1949 The course of foveal light adaptation measured by the threshold intensity increment. J. opt. Soc. Amer., 39, 172-179.

Baker, H. D., Doran, M. D., & Miller, K. E. 1959 Early dark adaptation to dim luminances. J. opt. Soc. Amer., 49, 1065-1070.

Hecht, S., Haig, C., & Chase, A. 1937 The influence of light adaptation on subsequent dark adaptation of the eye. J. gen. Physiol., 20, 831-850.

Mote, F. A. & Riopelle, A. J. 1951 The effect of varying the intensity and the duration of pre-exposure upon foveal dark adaptation in the human eye. J. gen. Physiol., 34, 657-674.

Wald, G. & Clark, A. B. 1937 Visual adaptation and the chemistry of the rods. J. gen. Physiol., 21, 93-105.