The Relation between the Electrical Excitability and the Duration of Illumination at the Peripheral Retina

By

Eietsu Suzuki

(鈴木 榮悦)

*From the Physiological Laboratory of Prof. K. Motokawa,
Tohoku University, Sendai*

(Received for publication, October 19, 1954)

INTRODUCTION

Motokawa¹⁾ found that the electrical excitability of the dark-adapted human retina becomes supernormal after an illumination of the eye. This supernormality depends upon various factors, among which the most effective is the intensity of illumination.

The relation between the intensity of illumination and the electrical excitability was investigated by Motokawa and Iwama²⁾, keeping the duration of illumination at 2 seconds.

Although it has been investigated by Mita *et al.*³⁾ and by Oikawa⁴⁾, how the electrical excitability of the eye changes at various durations of illumination, we have yet no systematic investigation extending over a very wide range of duration.

Ōba⁵⁾ studied this relation at the fovea, and obtained some interesting results.

The present investigation has been undertaken in order to establish a similar relation in the periphery of the retina.

EXPERIMENTAL

Method

The details of the apparatus and the procedure to determine electrical excitability are given in Motokawa's paper⁶⁾, so that only the principle of the method and some remarks on the procedure for determination of electrical thresholds of the eye will be mentioned here.

The electrical excitability of the dark-adapted eye after exposure to a photic stimulus increases temporarily, and this increase is taken as a measure for the effect of the illumination used. After a preliminary dark adaptation of about 20 minutes, the experiment was carried out. Stimulat-

ing currents, single constant current pulses of 100 msec. in duration were applied to the eye through a pair of silver electrodes by 2×1.5 cm². in size, placed one (the cathode) on the forehead slightly above the eye brow and the other (the anode) on the homolateral temple of the subject. The electrical threshold was measured in such a manner that from a sufficiently high level the stimulating voltage was reduced step by step until the subject could no more distinguish an electrical phosphene from the background of intrinsic light of the retina. A comparing procedure of Motokawa⁷⁾ was used when the subject told that a sensation of phosphene was uncertain. In this procedure the effect of each stimulus was compared with that of a control stimulus, i.e. one far below the threshold. In order to determine one threshold value it was necessary to repeat such a trial from 20 to 40 times. The threshold thus obtained is the reference threshold or threshold without pre-illumination.

The same procedure was carried out at a certain interval after the end of pre-illumination to obtain a threshold which was usually lower than the reference threshold when the interval was longer than 0.5 seconds. The increase in excitability caused by illumination was quantitatively expressed by ζ which is defined by the formula: $\zeta = 100 (E - E_0) / E_0$, where E and E_0 denote electrical excitabilities (reciprocal of thresholds) determined with and without pre-illumination.

An opaque glass disc of 1 cm. in diameter was illuminated from behind by white light and viewed from a distance of 45 cm., so that the visual angle subtended by the disc at the eye was $1^\circ 30'$. Between this opaque glass and the subject a sector was set in which an aperture of variable width was made in order to allow the light beam to pass the aperture as the sector was made to sweep like a pendulum. The durations of illumination were calibrated by means of a cathode-ray oscilloscope, connected with a D.C. amplifier and a photocell. Four different durations of illumination ranging from 40 to 200 msec. were prepared in this way. Durations longer than 500 msec. were made by opening and closing a shutter manually. In order to vary the intensities of illumination, the neutral wedge by Eastman Kodak Company was used. The other experimental conditions were quite similar to those described by Ōba⁵⁾ in the previous paper, except that the retinal area illuminated was limited to 20° from the foveal center of the left eye.

Results

The ζ -time curves, or the excitability curves for white light of various intensities are summarized in Fig. 1. In these experiments a flash of white light of 40 msec. in duration was given at 20° from the foveal center. The intensities of illumination used were 500, 100, 50, 20, 10, 1 and 0.1 lux

Fig. 1. Excitability curves obtained at periphery 20° with pre-illuminating white light of 40 msec. in duration at various intensities. Ordinates: percentage increases of electrical excitability above resting level. Abscissas: time in sec. after end of pre-illumination. Number of each curve indicates the intensity of pre-illuminating white light in lux.

from the top downwards. In this figure, percentage increases in electrical excitability of the eye over resting level are plotted as ordinates against times in seconds after termination of pre-illumination as abscissas. As the intensity of illumination is raised, the ζ -time curve increases in height. We can distinguish three elevations in the curves at lower intensities ranging from 0.1 to 20 lux, the first having a crest at 1.5 sec., the second at 3 sec. and the third at 4.5 sec. Based upon Motokawa's analysis⁽⁸⁾, it can be said that the elevations at 1.5 sec. and 3 sec. represent the yellow process (Y) and the blue process (B) respectively, while that having its maximum at 4.5 sec. after the onset of the flash represents the rod-process. The reasons were described in detail by Motokawa *et al.*⁽⁹⁾⁻¹¹⁾ In accordance with the result obtained by Oikawa and Kurosawa⁽¹¹⁾ no rod-process appeared in the excitability curve when the intensity of illumination was increased to 50 lux and thereabove. When such a high intensity as 500 lux was used, the green process (G) having its maximum at 2 sec. increased so much in height that the maximum of the curve was determined by G.

In the first place, it was attempted to study the relation between the magnitudes of the three elevations at 1.5, 3 and 4.5 seconds and the durations of illumination at different levels of intensity. The results are illustrated in Figs. 2 and 3.

In Fig. 2 ζ or percentage increases in electrical excitability of the eye over resting level determined 1.5 sec. after removal of pre-illumination, i.e. the magnitudes of the Y-process are plotted as ordinates against the logarithms of the durations of illumination as abscissas. As can be seen in this

Fig. 2. The dependence of magnitudes of Y obtained at periphery 20° upon logarithm of duration of pre-illumination. Number of each curve represents the intensity of pre-illuminating white light in lux.

figure, the magnitude of the Y-process increases as the duration of illumination is prolonged, at such lower intensities as 0.1, 1 and 10 lux the ζ -values increase almost in proportion to the logarithms of the duration and reach the highest level at 6 sec. At intensity-levels of 20 and 50 lux, a similar saturation is seen at 3 and 1.5 sec. respectively. For higher intensities such as 100 and 500 lux, the duration at which a saturation of ζ -value occurs is 0.5 seconds. Such critical duration for saturation will be called "saturation time." The shortest saturation time obtained in this experiment just coincides with that obtained at the foveal center for white light by Ōba⁵⁾.

Similar experiments were carried out with respect to the magnitudes of the B-process. The results are shown in Fig. 3, in which ζ -values de-

Fig. 3. The dependence of magnitudes of B obtained at periphery 20° upon logarithm of duration of pre-illumination.

terminated 3 sec. after termination of pre-illumination are plotted as ordinates against the logarithms of the durations of illumination as abscissas. As in Fig. 2, the ζ -values increase in proportion to the logarithms of the durations and become saturated at various critical durations according to the intensities used. The saturation times are 6 seconds at such lower intensities as 0.1, 1 and 10 lux, 3 sec. for 20 lux, 1.5 sec. for 50 lux and 0.5 sec. for 100 and 500 lux. Thus, no difference whatsoever can be seen between the data concerning the Y-and the B-processes, so far as the saturation time is concerned. The only difference consists in the highest magnitude of ζ for each intensity.

The saturation times found in Figs. 2 and 3 are plotted as ordinates against the logarithms of the corresponding intensities as abscissas in Fig. 4, in which we can distinguish two stable saturation times at 6 sec. and

Fig. 4. Saturation times of Y-and B-processes as a function of intensities of illumination.

0.5 sec. The former refers to intensities lower than 10 lux and the latter those above 100 lux, while the saturation time takes various values between the two extremities within the transition range from 10 lux to 100 lux.

It is to be noted that this range of transition approximately coincides with the range in which an interaction occurs between cones and rods at 20° from the fovea, as was shown by Oikawa *et al.*¹²⁾

These authors showed that as the intensities of light increased both cone- and rod-processes increased in magnitude, but that at a certain intensity about 10 lux the rod-process began to decrease and was completely suppressed above 100 lux.

DISCUSSION

In the previous paper, Ōba⁵⁾ investigated the relation between the electrical excitability and the duration of illumination at the foveal center.

The data obtained in his experiment indicated that the saturation times for monochromatic lights of various wavelengths were always 200 msec., while that for white light was 500 msec. over a very wide range of intensities. This finding could not be accounted for in terms of the energy of light absorbed.

As mentioned above, at intensities lower than 10 lux, the saturation time is always 6 seconds, and this range of intensities belongs obviously to the scotopic range. Oikawa¹³⁾ indicated that the Y-and the B-processes appear always hand in hand when achromatic sensations are elicited either by white or monochromatic light. Therefore the pair of Y and B in such achromatic vision was designated "twin-process". It is very likely that the two processes, Y and B found in the present experiment correspond to the twin-process designated by Oikawa. In other words, the two processes Y and B at the intensities of illumination of 0.1, 1 and 10 lux represent scotopic processes, although they take the same time course as the photopic yellow and blue processes. They are of dual character, having a scotopic spectral sensitivity on one hand and a time constant like the photopic processes on the other, as stated above. The fact that they are characterized by a longer saturation time indicates their scotopic character.

However, the magnitudes of ζ determined at 1.5 and 3 seconds after illumination become saturated at the same critical duration as found at the fovea, when the intensity of illumination exceeds 100 lux. From this fact it is very likely that they indicate the photopic processes although they were obtained in the periphery. In the intermediate region from photopic and to scotopic vision the two kinds of processes contribute to the measured magnitude of ζ in different proportions according to the degrees of excitation of both processes, so that the saturation time varies from 6 to 0.5 seconds. As was shown by Oikawa¹²⁾, the photopic process increases at the cost of the scotopic process, as the intensity of illumination is raised. The transition from 6 to 0.5 seconds in saturation time may be regarded as another expression of the rivalry between the photopic and the scotopic processes as revealed by Oikawa's experiment.

SUMMARY

Using the method of electrostimulation the relation between the electrical excitability of the eye and the duration of illuminating white light was studied at 20° from the foveal center.

The percentage increase in electrical excitability following an illumination was expressed by ζ . ζ -time curves consist of three elevations situated at 1.5 and 3 seconds from the end of illumination and at 4.5 seconds from its onset. The latter was designated "a rod process", while the process

with its crest at 1.5 sec. and that at 3 sec. were described as Y- and B-processes respectively.

1. The magnitudes of the Y-process increased in proportion to the logarithms of the durations of illumination, and at a certain critical duration they became saturated. These critical duration was called "saturation time". When the intensities of illumination were increased to 100 lux and above, the saturation time was always 0.5 seconds. This coincides precisely with that found by Ōba at the fovea.

2. The saturation times at such lower intensities as 0.1, 1 and 10 lux were always 6 sec., and in the intermediate region from 100 to 10 lux the value of saturation time varied from 6 to 0.5 seconds.

3. With the B-process quite the same result was obtained as with the Y-process.

4. The data were interpreted in terms of photopic and scotopic excitation of the retina.

I am greatly indebted to Prof. K. Motokawa for his many valuable discussions and kind guidance.

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