The Temporal Process of Subliminal Excitaory Level in the Light Detection

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In the studies of the light sense, it has long been known that the intensity (I) and the duration (T) of a flash at threshold are reciprocally related (Blondel & Ray, 1911; Karn, 1936). It has been infered from this fact that, within a limit of critical duration, the total energy (IT) of the flash is a determinant for the outbreak of the light sense, and that the temporal summation in visual system proceeds lineally from onset of flash to the threshold level, that is, the light quanta successively given to the visual system are photochemically summated (Hecht, Shlaer, & Pirenne, 1942; Long, 1951). On the other hand, it has been confirmed that the I-T relation in the light threshold is generally given by a form of $I=aT^n$, where a is a positive parameter and n is a negative one, and both the parameters are determined by the various factors, such as target size and adaptation level of the eye (Graham & Margaria, 1935, Karn, 1936; Piéron, 1952). From these findings, it seems to be difficult to explain the outbreak process of the light sense in terms of simple photochemical mechanism. There may be more complex processes.

From the past studies of I-T relation, it is possible to consider that a subliminal excitatory level in the light sense increases gradually as the time goes from the onset of flash to the light threshold. However, there have been few investigations on the visual excitatory level for a subliminal flash, and a general method for measurement of the excitatory level has not yet been established. The following three investigations give us a clue to contrive a method of measurement on the subliminal excitatory level.

Nakamura (1967) examined the visual excitatory after-effect for subliminal flashes as a function of temporal deley from offset of the flash. The index of the subliminal excitatory after-effect was the threshold duration of the second flash (test flash), which was presented after offset of the first subliminal flash with various interval. The independent variables were the intensity and the duration of the first flash, and the inter-flash-interval between the two flashes. It was found that the minimum inter-flash-interval reqired for the extinction of the excitatory after-effect becomes longer as the intensity or the duration of the first flash increases. It was confirmed through the statistical test of his data that there is a significant correlation between the inter-flash-interval required for the extinction of the excitatory after-effect and the relative duration of the subliminal flash to the threshold duration, even though the intensity of the flash is varied.

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Battersby & Defabaugh (1969) made a study on the visual excitatory remainder for a subliminal conditioning flash with the intensity of 55 percent of the threshold level, as a function of temporal delay from the offset of the conditioning flash. The index of the excitatory remainder was the threshold intensity for a 5 msec test flash, which was presented after the offset of conditioning flash with various inter-flash-interval. Battersby & Schuckman (1970) measured the threshold intensity for a 5 msec test flash as a function of the duration of subliminal conditioning flash, under a stimulus condition that the test flash was presented immediately after the offset of conditioning flash. The relative threshold intensity of the test flash was used as a index of the excitatory effect for the conditioning flash, though they did not so much emphasize the conception of the excitatory effect in their paper. Their results indicated that the subliminal excitatory effect for the conditioning flash did not depend upon both the total energy of the flash and the relative intensity to its threshold intensity.

On the basis of the above mentioned Nakamura's finding, it is possible to assume that a determining factor of a subliminal excitatory level is the relative duration to the threshold duration, not the total energy of the flash or the relative intensity to the threshold, that is, if several subliminal flashes are alike in the ratio of subliminal duration (T_s) to the threshold duration (T_o), the excitatory levels for the flashes will be almost the same. The present study was intended to investigate the adequacy of the above mentioned assumption that the subliminal excitatory levels depend upon the relative duration (T_s/T_o), through the summation effect of two successive subliminal flashes, and to consider the visual mechanisms of the threshold level in the two-flash summation based on the total energy of the two flashes.

Battersby & Shuckman (1970) used the relative intensity ($\Delta I_c/\Delta I_o$) of the threshold intensity (ΔI_c) of test flash in the two-flash summation to the threshold intensity (ΔI_o) for the test flash alone, as an index of the excitatory level for the subliminal conditioning flash. It is also reasonable to consider that the difference between ΔI_o and ΔI_c indicates some visual excitatory level induced by a subliminal flash. In this paper, the value of $(\Delta I_o - \Delta I_c)/\Delta I_o$, E_a, is used as an index of the excitatory level for a subliminal flash. When ΔI_s is equal to ΔI_o, the excitatory level is zero, and when ΔI_c is zero, the value is one. However, the term of the excitatory level is not necessarily understood in its physiological context.

Method

Apparatus

The maxwellian-view optical system was used to present light stimuli, as shown in Fig. 1. The optical system consisted of three pathways, one of which (W_1) was provided for a constant adapting field and the other two (W_2, W_3) were for

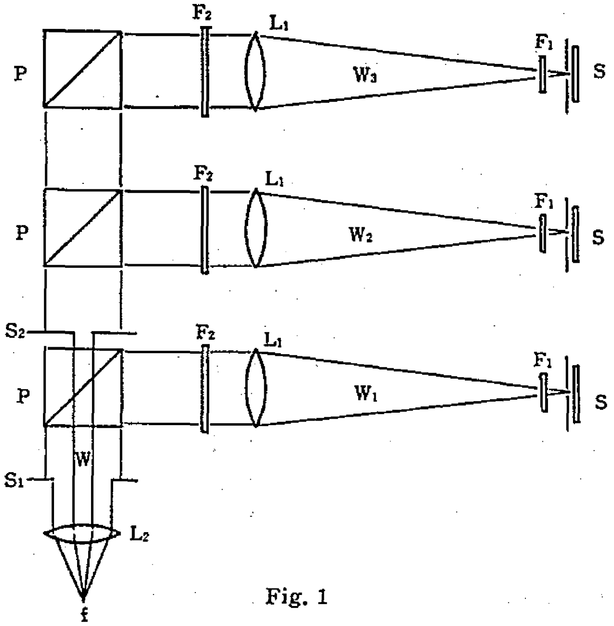

Fig. 1

the conditioning and the test flash. Each of the three beams radiated from the fluoescent lamps (S) passes through a pinhole, and is collimated by a concave lens (L_1), and is collected into one common pathway (W) by right-angled beam-splitter (P), then converges to a focus (f) through another concave lens (L_2).

The intensity of each beam, which was checked with the luminance meter (Sanso, 12A), was adjusted by means of the two neutral density filters, one of which (F_1) was a circular wedge and was used to increase or decrease the intensity of the light, another one of which (F_2) was to decrease it by a factor of 1/10 or 1/100. The fluoescent lamps (NEC, FL4D) were connected to the electric powers of the tachistoscope (Takei, TR). The forms of the lights radiated from the middle of the fluoescent lamps were approximately rectangular, as a result of examining them by the oscilloscope. Their rising times were one msec, and the falling times were less than one msec. The exposure duration of the light was controled by a time control circuit of the multi-unit-system (Takei), and the starter of the time control circuit was operated by another time controller. The time regulator also adjusted the duration of the warning tone generated by an oscillator and the interval of the tone offset to the onset of the conditioning or of the test flash. A slit (s_1) circumscribed the adapting field, and another slit (s_2) the conditioning and the test flash. The times from the onset of the first flash to the response by the subject, RTs, were measured to the millisecond by means of the digital timer (Takei, TW-7010A). An electric key for the response was set up on a table and near the subject's right arm. However, the results of reaction time is not mentioned in this paper.

Measurements of threshold durations

Stimulus and procedure. The present experiment was designed to determine the threshold durations for the flashes with different intensities. The durations of subliminal conditioning flash to be used in the main experiment were calculated from these threshold durations.

Intensity and size of the adapting field were held constant through this experiment; one troland (retinal illuminance) in intensity, and 17°30′ in visual angle. The size of the test flash was fixed at a visual angle of 2°40′ in diameter, and was superimposed upon the center of the adapting field. These fields were circular in shape.

A mean threshold duration for each of four intensities of test flash was determined from twenty threshold measurements for each subject, using the up-and-down method (Guilford, 1954). In the measurement of the threshold duration, the duration of test flash was increased or decreased in step of .079 log msec in each trial. Each trial began with a 300 Hz warning tone lasting 2 sec, followed by a test flash after an interval of 2 sec, then goes to the next trial with about 10 sec interval after the offset of a test flash. The experiment for each subject was divided into two sessions, each of which contained eight blocks. One block consisted of five threshold measurements for a constant intensity. The four intensities were used twice in random order in one session. A two minute rest was taken after each block. The two sessions were separated by a ten minute rest, and were run within a period of an hour and a half. In advance of the beginning of the experiment, subjects were asked to be seated and to dark-adapt for ten minutes. Then they were instructed to settle the right eye at a beam focus by putting their head on the head holder, and to fixate the center of adapting field continuously during the measurements of one block, and to press the key as fast as possible with their forefinger of right hand, whenever a flash was detected in the center of the adapting field at about two seconds after the offset of warning tone. A reaction time was measured at the same time as the threshold measurement. Ten practice trials for a super-threshold flash were given to each subject before the recorded trials started. The subjects employed were three male students majoring in psychology. They all had normal acuity.

Results. Table 1 shows the mean threshold durations as a function of the intensity of flash, and the relations of the intensity and the duration for each of three subjects. The durations of subliminal flashes used in the main experiment will be calculated on the basis of these threshold durations.

The threshold duration decreases as the intensity of flash increases. The relations between intensity and duration for three subjects can be expressed by a equation of $I = aT^n$. This equation can be transformed as follows: $\log I = \log a +$

$n \log T$. The values of a and n for three subjects were obtained from an apprication of the least squares method to the logarithmic values of the intensities and of the threshold durations shown in Table 1. The values of n for three subjects were $-.66$, $-.83$, and $-.60$, and those of a were 4.76, 13.10, and 3.12, respectively. The absolute value of n was less than unity in any subject. The predicted value of T for each of four intensities was calculated by substituting the values of I, n, and a into the equation $I=a\,T^{n}$, for each subject. Consequently, it was confirmed that the predicted values of T were very close to the experimental ones. The maximum difference between the two values was 10 msec.

TABLE 1

The mean threshold duration T (msec) for each intensity I (troland)

I \ Subject	N	M	K
.444	—	61	—
.296	63	90	53
.242	100	—	—
.198	—	152	91
.161	159	204	141
.131	227	—	202
I–T relation	$I=4.76T^{-.66}$	$I=13.10T^{-.83}$	$I=3.12T^{-.60}$

Experiment

Stimulus and procedure

The following steps were taken to examine the visual excitatory level for subliminal flash at some point of time (t) after the onset of flash.

In the experimental condition, a 5 msec test flash was presented immediately after a subliminal conditioning flash with some duration (t) and some intensity (I_c), and a threshold intensity (ΔI_e) for the test flash was measued in the two-flash summation (Fig. 2). The conditioning and the test flash were the same size as the test flash used in the preliminary experiment, i.e., the circle of 2°40′ visual angle in diameter, and were concentrically superimposed upon the central position of the circular adapting field, which is 17°30′ in visual angle and one troland in intensity.

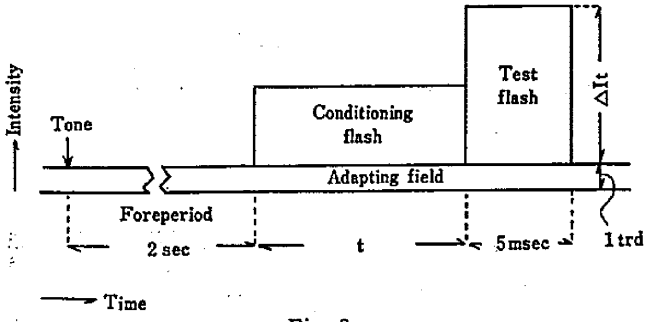

Fig. 2

The four intensities of the conditioning flashes were used for each subject (see Table 1), and thier durations were decided to be 1/8, 2/8, 3/8, 4/8, 5/8, 6/8 and 7/8 of each threshold duration shown in Table 1. That is, twenty-eight conditioning flashes (4 intensities × 7 relative durations) were used in this experiment for each subject.

The seeing probabilities for the conditioning flashes with 1/8 to 6/8 relative durations were zero in any subject, but those with 7/8 relative duration ranged from .10 to .40 according to subject and intensity of flash; so the ΔI_c values for the conditioning flashes with 7/8 relative duration were measured by a method different from that for the other relative durations. In the relative durations of 1/8 to 6/8, the mean threshold intensity (ΔI_c) of test flash was obtained from twelve measurements for each of the twenty-four conditioning flashes with the up-and-down method, in which the intensities of test flash were increased or decreased in steps of .088 log troland. Each subject served in four sessions. One session consisted of twelve blocks of six threshold measurements each. One intensity and one duration of the conditioning flash was used in each block. In the twelve blocks of each session, the intensity and the duration were varied in random order, by such a way that two successive blocks were always different either in intensity or in duration. Each of the twenty-four combinations of intensity and duration consisted of two blocks. Each session was separated into two parts by an about 10 minute rest, and was run within an hour and a half. A rest-period of about two minutes was given after each block. After these experiment were over, a mean threshold intensity (ΔI_c) of test flash for each of four conditioning flashes with 7/8 relative duration was obtained from twenty threshold measurements, for each subject. It was impossible to use the up-and-down method in this measurement, so the mean threshold intensity was obtained by the linear interporation, using the method of whole series.

In the control condition, twenty threshold intensities for only the test flash of 5 msec were measured for each subject by the same method as in the experimental condition, and their mean threshold intensities (ΔI_o) were calculated from these values.

The same three subjects as in the preparatory experiment were used. The other stimulus conditions and the instruction to the subjects were the same as in the preparatory experiment.

Results.

Fig. 3 presents the values of excitatory level E_a, $(\Delta I_o - \Delta I_c)/\Delta I_o$, as a function of relative duration (D_r) and intensity (I_c) of the conditioning flash, for each subject. The predicted values of E_a for the relative duration of zero and of one were indicated by the crossed marks on the graphs. When the duration of conditioning flash is zero, the value of ΔI_c should be equal to ΔI_o, and the value of E_a will be zero. When the duration of conditioning flash is on its threshold, the relative duration is one, and ΔI_c should be zero, then the value of E_a will be one.

As shown in Fig. 3, the values of E_a are very close to zero in the 1/8 and 2/8 relative durations and increase from 3/8 to one relative duration with about constant gradient. The four values of E_a in each relative duration are very similar irrespective of the intensity of conditioning flash. These tendencies are reconfirmed by the following statistical tests.

The values of E_a were analyzed by 4×7 analysis of variance with the relative duration and the intensity of conditioning flash as the sources of variance, in each subject. The relative duration effect was significant ($F=416.61$, 194.35, 241.29, respectively for three subjects, $df=6/18$, $p<.01$), but the intensity effect was not significant ($F=.71$, 3.30, 3.04, $df=3/18$), in each subject. From these findings, we can conclude that a value of E_a depend upon the relative duration of subliminal

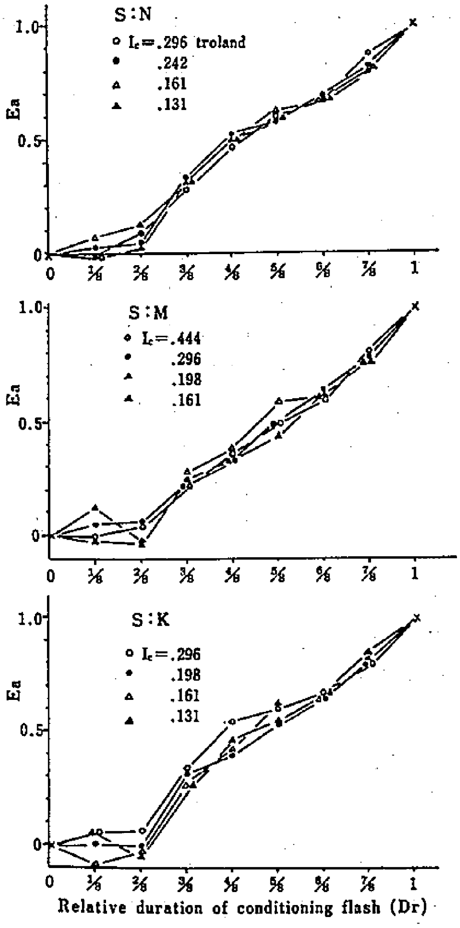

Fig. 3

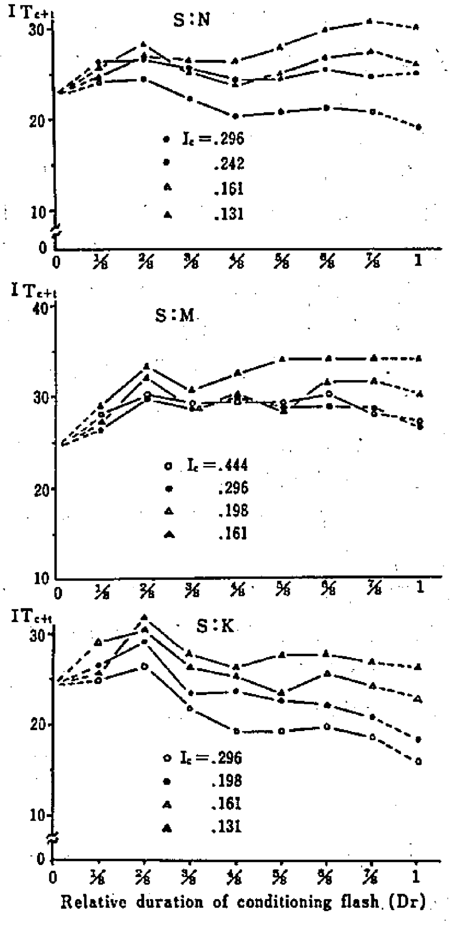

Fig. 4

flash irrespective of the value of its intensity.

The difference between zero and the mean value of E_a in each of 1/8 and 2/8 relative duration were not statistically significant, except that for 2/8 relative duration of subject N ($t=3.482, df=3, p<.05$).

We shall now examine the total threshold energy in the summation of two subliminal flashes; namely the sum of the energy for the conditioning flash and that of the test flash. Fig. 4 shows the total threshold energy (IT_{c+t}) of the conditioning and the test flash ploted as a function of the relative duration and the intensity of the conditioning flash, for each subject. The value of IT_{c+t} for a zero relative duration in each graph, IT_t, is shown by the value of threshold enegy for a 5 msec test flash alone, and the value of IT_{c+t} for a one relative duration, IT_c, is the threshold energy for a conditioning flash alone, and their values are shown by the crossed marks on the graphs.

A tendency is found in Fig. 4 that the value of IT_{c+t} in each relative duration increases as the intensity of conditioning flash decreases, and that, in one intensity of conditioning flash, there are not notable difference in the five values of IT_{c+t} of 3/8 to 7/8 relative duration, but the values for 1/8 and 2/8 relative duration are not always the same as others. These tendencies were ascertained by the following statistical tests.

The values of IT_{c+t} were analyzed by a 4×7 analysis of variance with the relative duration and the intensity of the conditioning flash as the sources of variance, for each subject. The effect of intensity was signficant in any subject ($F=16.90, 19.72, 32.53$, respectively, $df=3/18, p<.01$). The effect of relative duration was significant for subject M and K ($F=6.18, 13.75, df=6/18, p<.01$), but was not for subject N ($F=1.16, df=6/18$). Then, the twenty values of IT_{c+t} for 3/8 to 7/8 relative duration were submitted to a 5 relative durations ×4 intensities analysis of variance, for each subject. Consequently, the effect of intensity for three subjects were significant ($F=41.34, 15.49, 67.48$, respectively, $df=3/12, p<.01$), but the effect of relative duration was not significant ($F=2.75, 1.47, 3.36, df=4/12$) in any subject.

The values of IT_{c+t} in Fig. 4, in the result of subject M, are larger than the value of IT_t, but in subject N and K are distributed up and down according to the value of relative duration As far as this result indicates, it is difficult to find a certain relation among IT_t, IT_c, and IT_{c+t}.

Discussion

In this study, it was found that with a certain temporal limit the visual excitatory level for a subliminal flash is determined by the value of the relative duration of the flash, even under differnt intensity of the flash. This finding supports the assumption offered in the beginning of this paper.

However, there is a suspicion that a determining factor of the subliminal excitatory level is the total energy (It) of the flash, and that its relative duration is a secondary factor for the determination of the excitatory level, even though Battersby & Schckman (1970) found that the excitatory effect for subliminal flash does not depend upon the energy of the flash. If the values of threshold energy for some flashes are constant for any intensity of flash, that is, if the value n in the formula $I=aT^n$ is minus one, the total energy of subliminal flash is proportional to the relative duration of the flash irrespective of its intensity. Therefore, when the value n is minus one, that the subliminal excitatory level depends upon the relative duration means that it depends upon the energy of the flash. When the value n takes other value than minus one, the energy of the subliminal flash is not proprotional to the relative duration. Then, when the value n is not minus one, it is impossible that the subliminal excitatory level for a flash depends upon both the relative duration and the energy of the flash.

The values of n obtained in this study were $-.66$, $-.83$, and $-.60$ respectively for the three subjects. These values are apparently larger than minus one. Therefore, it is probable for us to conclude that a determining factor of the visual excitatory level for a subliminal flash is not the energy of the flash but its relative duration, in the context of the present experiment.

As shown in Fig. 3, any increase of the subliminal excitatory level does not appear in 1/8 and 2/8 relative duration, and the excitatory level increases linearly from 3/8 to 7/8 relative duration. This phenomenon is seen throughout the three subjects. Here, it may be considered that even in a smaller relative duration than 2/8 there is some latent physiological excitability, which has some effect on the visual excitement, though it was not shown in this experiment. In any case, the increasing rate of excitatory level at the beginning of flash will be fairly small compared with that in the later period. Therefore, it is quite improbable that the temporal subliminal process in the light detection increases linearly from the onset of light to the threshold level.

We can reconsider the results in the present experiment from the view point of the temporal summation of two subliminal flashes. The investigations of the temporal summation in the light sense have been done by many researchers (Granit & Davis, 1931; Davy, 1952; Ikeda, 1965; Barlow, 1958; Uetsuki & Ikeda, 1970). An important problem in their studies was the applicability of Bloch's law to the summation of two subliminal flashes. In their studies, the two subliminal hflases which are equal in intensity or in duration were presented with various inter-flash- intervals, and the total energy of the two flashes in threshold was measured for each interval. Their results generally indicated that Bloch's law helds for an inter-flash- interval less than about 20 msec. In the present study, the inter–flash–interval fixed at zero through the experiment, but Bloch's law did not rarely held for any subject. As shown in Fig. 4 the values of total threshold energy (IT_{c+t}) of two subliminal flashes vary according to the intensity of the conditioning flash. The two subliminal flashes used in the present experiment were different both in intensity and in duration. In such a condition, there may be a more complex mechanism in the two–flash summation of the visual system.

Let us now consider the methods for study of the subliminal excitatory process. Battersby & Schuckman (1970) investigate the time course of temporal summation by measuring the threshold intensity for a 5 msec test flash as a function of the intensity of subliminal conditioning flash and the interval between onset of the conditioning flash and onset of test flash, in five steps from zero to 100 percent of the duration of the conditioning flash. Their result generally indicated that the threshold intensity of test flash was high at early delays, and that it fell to a minimum in the middle of exposure of conditioning flash, and then rose again at the termination of its duration. Their finding appears to be in disagreement with the result in the present study, but this disagreement seems to be due to the difference in the temporal arrangement of the conditioning and the test flash. In the present study, test flash was presented immediately after the offset of conditioning flash. The method used in the present study seems to be fit for the measurement of the excitatory effectfor a subliminal flash.

There are many problems to solve in the study on the temporal process of visual excitatory level. One of the problems, for example, is whether the law of subliminal excitation that the excitatory level for subliminal flash depends upon the relative duration of the flash is applicable in such a complex detection as letter detection. If the law is applicable to the more complex detection, the law should be reconsidered as that in the central level in the visual system.

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