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VISUAL MASKING BY LUMINANCE INCREMENT AND DECREMENT: EFFECTS OF RISE TIME AND DECAY TIME

By

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With the increment threshold technique the masking functions were obtained from 6 *S*s under the four rise time conditions of the incremental MS (masking stimulus) and the four decay time conditions of the decremental MS in separate two experiments. The rise time and the decay time were varied in four steps, respectively; 0, 50, 100, 200 msec. Results of Experiment I where the effects of the rise time on the masking effect were examined revealed that (1) the masking effect at the peak decreased proportionately with the length of rise time, (2) the masking peak appeared later in time as the rise time became longer, although this was not the case with one *S*, and (3) the shape of the function became roundish around the peak and additional one or more peaks were found for longer conditions of rise time. Results of Experiment II where the effects of the decay time on the masking effect were exmained showed that (1) no remarkable change in the magnitude of the masking peak was found even when the decay time was increased, (2) the masking peak was at the offset of MS under the shortest decay time condition but was delayed by 10–25 msec after the beginning of the MS decrement for the other longer conditions of decay time, (3) the slope of the function following the peak became gentle depending on the length of decay time. These results were compared with those which had been obtained with the usual stepwise increment or decrement MS and discussed in terms of visual on- or off-responses described by Boynton.

Introduction

A change in the level of luminance of a given field produces a complex visual effect. When increment thresholds for detecting the small test flash superimposed on the larger field whose luminance varies between two levels are measured before, at and after the change in luminance of the latter field, a complex threshold curve is obtained. These visual effects were reported first by Crawford (Crawford, 1947) and traditionally investigated in the context of the early light and dark adaptation (Baker, 1963).

The increment threshold curve has been called the masking function by Kahneman (Kahneman, 1968), and this terminology was used in the present paper. Also the test flash was abbreviated to TF and the larger field, whose effects were being evaluated by TF, was called MS (the masking stimulus) according to Kahneman.

The masking function associated with the sudden increase in luminance (the stepwise increment MS) has been reported to be composed of the following four stages (Boynton, 1957; Baker, 1963). (1) 100 msec or less before the onset of MS, the TF threshold begins to rise abruptly (the backward masking). (2) The TF threshold reaches a peak at the onset of MS or with some delay from the MS onset. (3) The threshold declines relatively fast during first 100–200 msec after passing the peak. (4) Then thresholds decrease relatively slowly, until it finally reaches a stable light-adapted value. Occasionally it was reported that the TF threshold was paradoxically lowered slightly when TF preceded MS onset by 100–150 msec and this effect was called the backward sensitization by Sperling (Boynton, 1963; Sperling, 1965).

On the other hand, when the prevailing luminance of MS was suddenly decreased, masking functions obtained were similar, in the stages involved, to those associated with the increment MS, but different in some aspects from them. The masking function associated with the sudden decrease in luminance (the stepwise decrement MS) is composed of four stages which are as follows (Baker, 1963; 1973): (1) The TF threshold begins to rise slowly 100 msec or less before the offset of MS. (2) Approximately at the MS offset the threshold rise reaches a peak. This threshold rise is small and is missed under certain conditions. (3) The threshold declines abruptly during first 100–200 msec after the MS offset. (4) This third stage then levels off into the fourth, slow decline stage which is the traditional dark-adaptation curve. Phenomenally the same effect as the backward sensitization which appears in the masking by the increment MS can be sometimes obtained about 100 msec before the MS offset (Baker, Doran, & Miller, 1959). These stages were also reported in the studies on the letter detection masking by the luminance decrement or the light offset (Boynton, 1963; Holzworth & Doherty, 1971; 1974).

Similarity of the stages involved are remarkable between two masking functions associated with the increment and decrement in luminance. But they differ in several points. Masking effects are generally more prominent in the masking by the increment MS and more susceptible to the influences from the degree of the variation in luminance than in the masking by the decrement MS (Baker, 1963). The masking by the increment MS developes rapidly and declines relatively slowly whereas the masking by the decrement MS shows a relatively slow rise and a sharp decline (Ikeda & Boynton, 1965).

In the almost all studies cited above, the increment and decrement of MS were very abrupt, that is, the employed temporal stimulus wave form of MS was a rectangle or a stepwise one. It is the principal aim of the present study to examine how each of the stages of masking functions is altered when the rise time and the decay time of MS are varied.

In the preceding paper (Matsumura, 1975) masking functions were obtained for three brief flashes which were equal in the total amount of energy change but differed in the distribution of luminance in time (the temporal waveform). The result relevant to the present study was that the temporal position of the peak of the masking function moved in accordance with the rise time of MS. This implies that the rise time may be closely related with the peak latency of the masking function.

The use of the brief flash as MS in that study makes the interpretation difficult because the increment and the decrement in luminance are so close in time that it is impossible to separate the masking by the increment from that by the decrement. In the present study relatively long and temporally trapezoidal flashes were employed as MSs in order to vary the rise time and the decay time. The effect of the rise time on the masking by the increment MS and that of the decay time on the masking by the decrement MS were examined in separate two experiments.

Method

The apparatus and the procedure employed in the present experiment were nearly the same with that used in the preceding work (Matsumura, 1975), except for the experimental conditions of MS.

The rise time (Experiment I) and the decay time (Experiment II) of MS were varied in four steps, respectively; 0 (the usual stepwise change), 50, 100, and 200 msec. These were obtained from four temporally trapezoidal flashes of approximately one second duration at the baseline luminance in each experiment. The *rate* of the increase or decrease in luminance in a certain rise or decay time was constant and therefore the luminance was linearly increased or decreased in time. To avoid unexpected influences from the condition of an irrelevant extreme of MS, now not the object of the examination, particularly the influence of the on-effect on the off-effect, the rise or decay time of this irrelevant extreme was held constant at 200 msec. Fig. 1 shows the MSs employed in two experiments. These temporal wave forms of MSs were obtained with the use of "the method of frequency-modulation of glow train". The voltage trapezoids (0↔+4V) generated from a function generator were fed into a V-F transducer, hence obtaining a frequency modulated pulse train (200↔1000 Hz). Each pulse in a

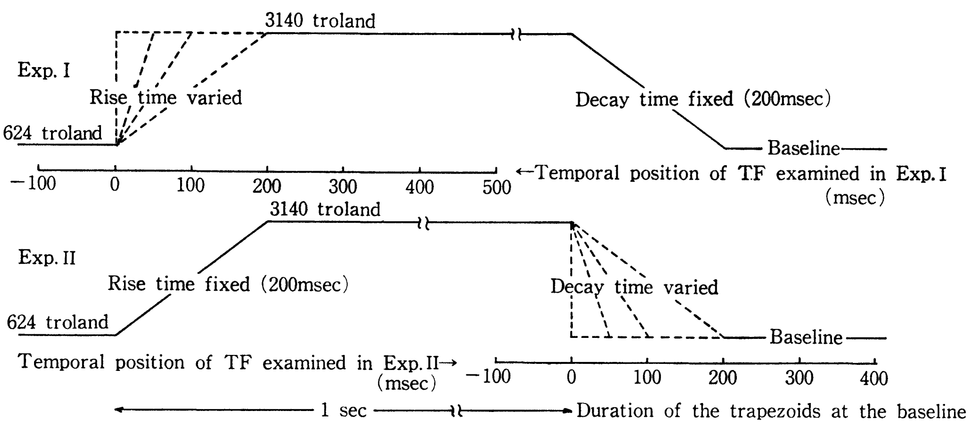

Fig. 1. Schematic representation of the experimental conditions of the MS employed in the present two experiment. Upper trapezoids were used in Exp. I where the rise time of the MS was varied and the decay time was fixed. Lower trapezoids were used in Exp. II where the decay time of the MS was varied and the rise time was fixed.

pulse train was made to have the equal pulse duration by way of a pulse generator and drove the glow modulator tube after its being amplified. Thus temporal waveforms of MSs were obtained. The luminance change ranged 628 to 3140 trolands at the eye (200 to 1000 nit). The lower level of luminance was used as the pre- and post-adaptation field of MS.

TF was a circular spot subtending a visual angle of 1.72°, superimposed on the center of MS field, a disk subtending a visual angle of 6.73°. The light sources of both TF and MS were separate glow modulator tubes and they were presented to the *S*'s left eye through the dual beam Maxwellian view system. The central fixation was employed on the cross-hair attached to the field stop of one channel.

Luminance increment thresholds of TF, of 2 msec duration, were measured at various temporal points before, at and after the beginning of the increment (Exp. I) or that of the decrement (Exp. II) in MS luminance. A given phase-locked sequence of MS and TF was repeated once every 5 seconds. While *S* were looking at this sequence through an artificial pupil of 2 mm diameter, the TF luminance was decreased from the level on which *S*s could see TF clearly. This change in the TF luminance was performed step by step with a circular neutral density wedge rotated by a pulse motor and *S* stopped this motor at the disappearance of TF. Thus only descending series of a modified method of limits were employed.

Each experiment consisted of four sessions. All four conditions of rise time or decay time were examined within a given session. For a certain rise time (or decay time) condition the TF thresholds at all temporal positions were measured in a block, and at each temporal position of TF, the only two thresholds were determined in order to save the time. In addition to these thresholds relevant to the experimental condition, the TF thresholds against a constant level of MS luminance of 628 trolands were measured before and after the examination of a given condition in order to check the change in the resting level. Such a session was repeated four times and the presentation orders of conditions and of temporal positions of TF were counterbalanced between sessions. The plotted points in the graph are the means of eight values obtained from four such sessions.

Six *S*s, three in Exp. I and the other three in Exp. II, were participated in the present study. They had normal or normal corrected vision and were trained well for this work.

Results

Experiment I: Effects of the Rise Time on the Masking by the Increment MS

Masking functions for four conditions of the rise time were plotted in Fig. 2, where each graph represented the result of each condition of the rise time obtained from three *S*'s; (a) 0 msec, (b) 50 msec, (c) 100 msec, and (d) 200 msec. Data of MM and those of JG were shifted downwards by 0.5 log unit and 1.0 log unit, respectively, in each graph. Abscissae indicate the temporal position of TF and the origins are the

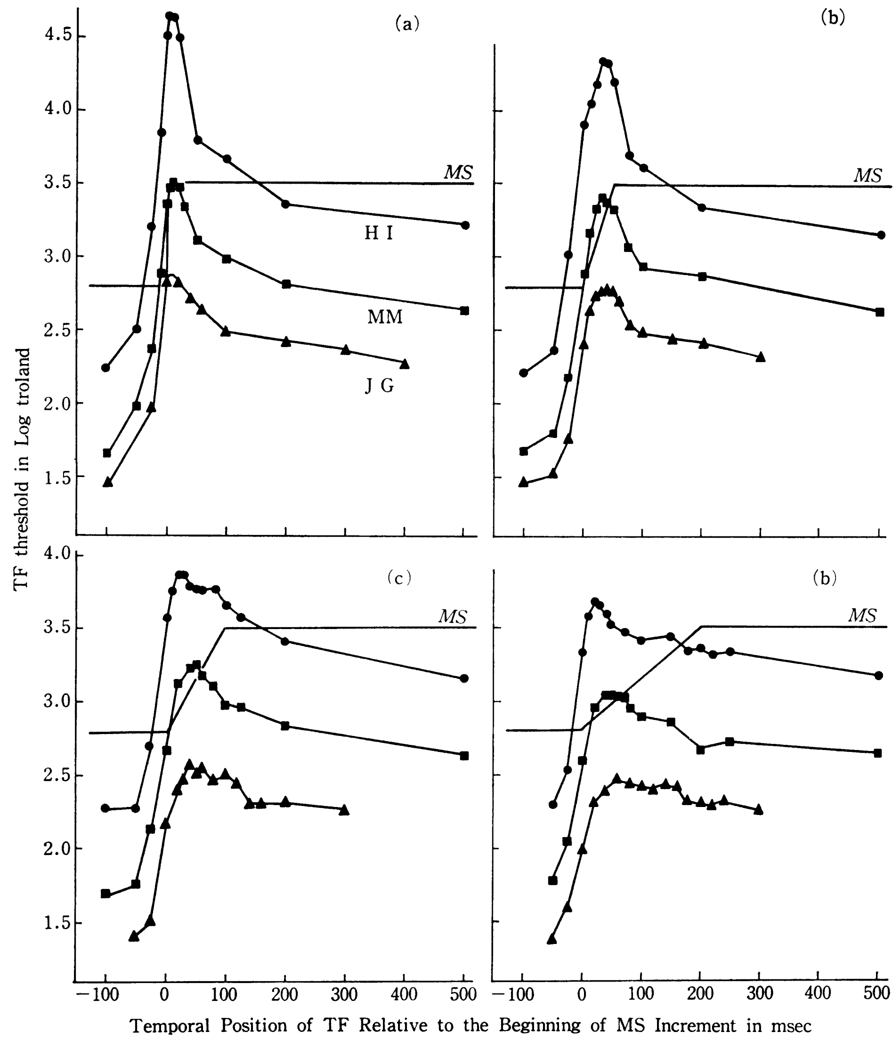

Fig. 2. Masking functions for 4 conditions of rise time: (a) 0 msec, (b) 50 msec, (c) 100 msec, and (d) 200 msec. Results from 3 *S*s. Solid lines below *MS* indicate the masking stimulus employed actually.

points where the onset of TF coincides with the beginning of the MS increment. Results were redrawn in Fig. 3, where masking functions of four rise time conditions were overlapped for each *S*.

These figures showed that the four essential stages found in the earlier studies could be obtained generally even when the rise time was varied. As the rise time of MS became longer, however, masking functions varied systematically in several respects. First, the longer the rise time was, the smaller the masking effect at the peak was. The decrease in the peak magnitude of the masking function was proportional to the length of the rise time. Under the 0 msec condition the change in the TF threshold from the

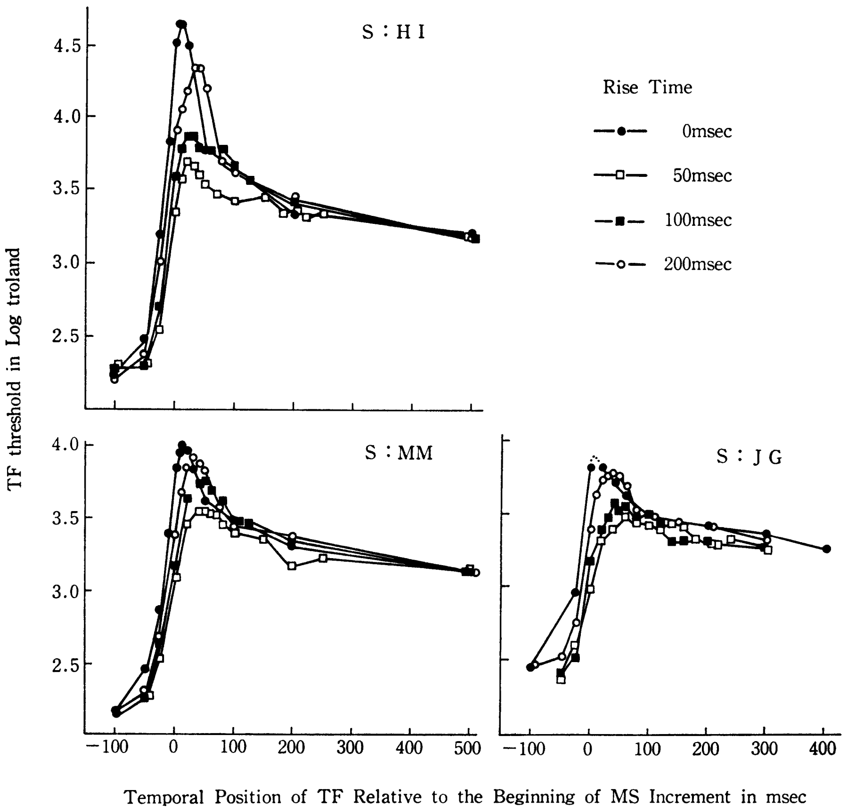

Fig. 3. Replotted masking functions of Fig. 2. for each *S*.

resting level to the peak extended by 2 long unit or more whereas under the 200 msec condition it was 1.5 log unit or less. Thus the difference in the peak values of the two extreme conditions was about 0.5 log units.

Secondly, it took longer time for the peak of the masking function to appear as the rise time was lengthened, although this was not the case with the subject HI. As to the data of MM and JG, the temporal positions of the peak obtained under four conditions were in the range of 5–10 msec (under the rise time of 0 msec), 30–40 msec (50 msec), 40–50 msec (100 msec), and 50–60 msec (200 msec) after the beginning of the MS increment, respectively. On the basis of such values anyone can calculate the amount of the energy change required during the interval between the beginning of the MS increment and the appearance of the peak in each rise time condition. Result of these calculations was that such energy change was nearly constant in the all four conditions of rise time, being approximately 7000 troland·msec.

Thirdly, the shape of the functions around and after the peak varied depending on the length of the rise time. As to the shorter conditions of rsie time (0 and 50 msec) the peak was sharp and the decline of the TF threshold after the peak was monotonic, while the shape around the peak was roundish and there were additional one or more

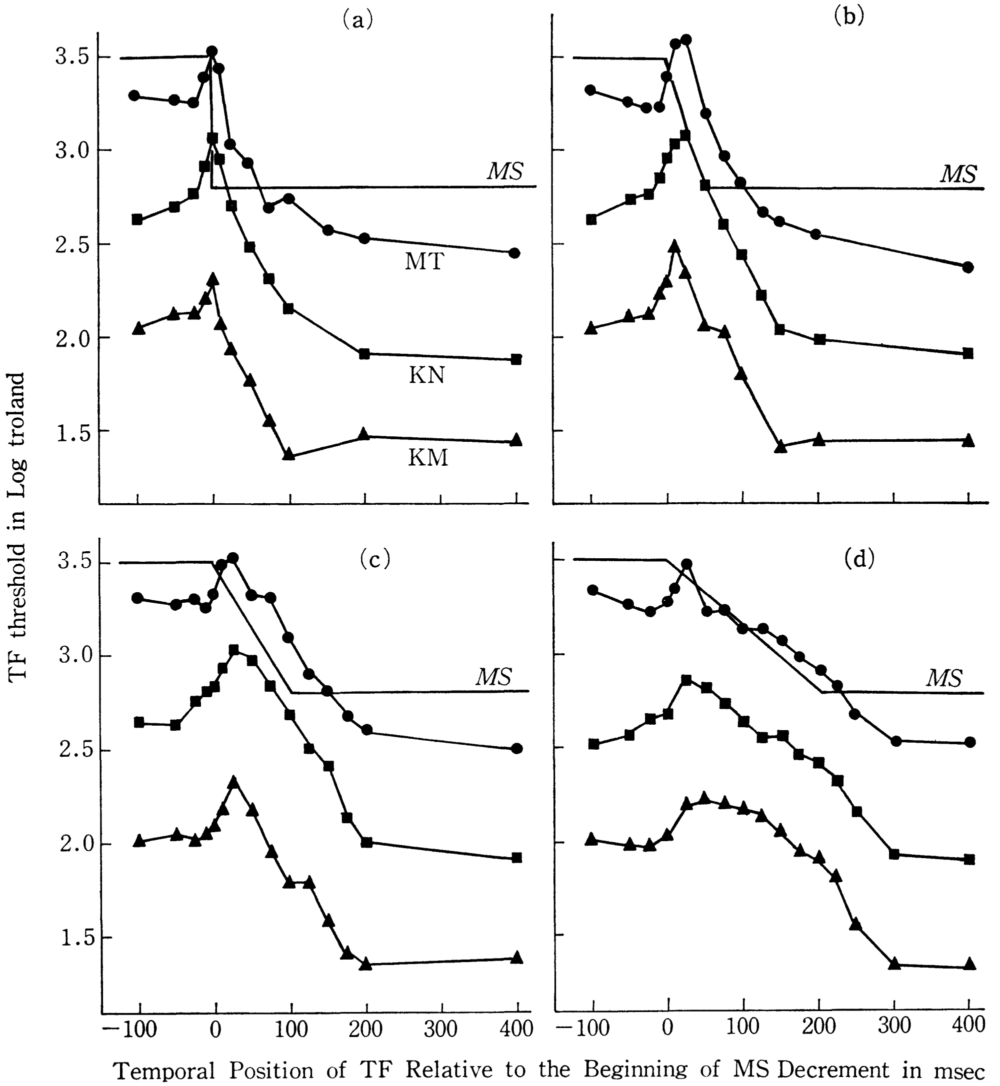

Fig. 4. Masking functions for 4 conditions of decay time: (a) 0 msec, (b) 50 msec, (c) 100 msec, and (d) 200 msec. Results from 3 *S*s. Solid lines below *MS* indicate the masking stimulus employed actually.

small rises in the threshold after the first peak for longer conditions of rise time (100 msec and 200 msec).

Experiment II: Effects of the Decay Time on the Masking by the Decrement MS

Fig. 4 showed the masking functions under four conditions of decay time of MS. Each graph in Fig. 4 represented the result of each condition of decay time obtained from three *S*s; (a) 0 msec, (b) 50 msec, (c) 100 msec, and (d) 200 msec. Abscissae

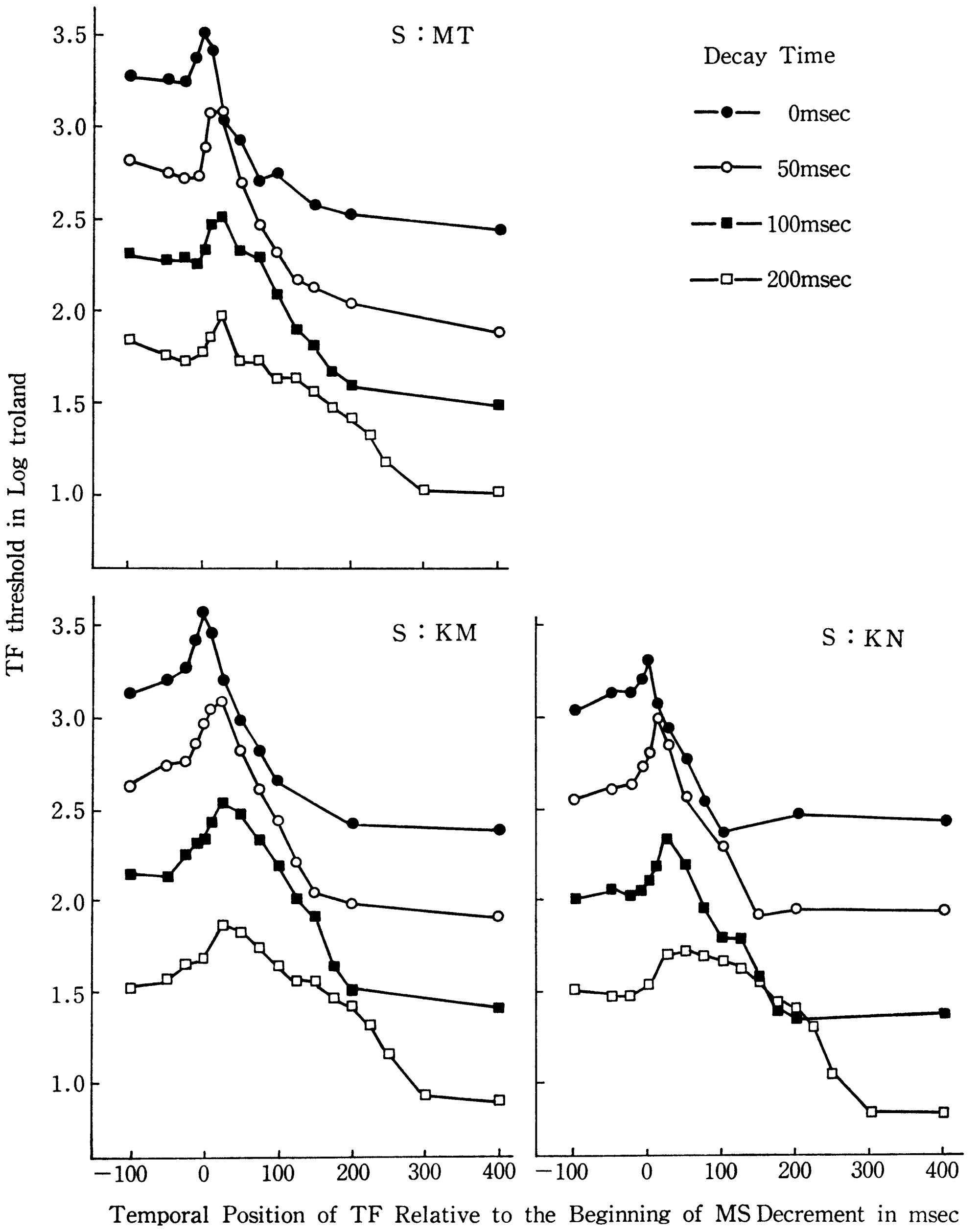

Fig. 5. Replotted masking functions of Fig. 4. for each *S*.

indicated the temporal position of TF relative to the beginning of the MS decrement. In each graph the curve for subject KN and that for KM were lowered 0.5 log unit and 1.0 log unit, respectively, to avoid overlapping the curve from subject MT. Results in Fig. 4 were redrawn in Fig. 5, where masking functions of four decay time conditions were plotted in group for each *S*s. The scale of the ordinates was for 0 msec condition and plots of the other three conditions were shifted downward by 0.5 log units in the order from shorter to longer decay time conditions.

Typical four stages of the masking function associated with the usual stepwise decrement MS were found under every decay time condition as shown in these figures. No remarkable change in the magnitude of the masking peak was found even in the increase in decay time, and even when the decay time was lengthened up to 200 msec, a small rise of the TF threshold was clearly still present. The temporal position of the peak was at the offset of MS under 0 msec decay time condition but was 10–25 msec after the beginning of the MS decrement under the other longer conditions of decay time. The stage following the peak, where the TF threshold declined abruptly (the third stage described in the introducing section), depended upon the decay time variation of MS. As the decay time became longer, the TF threshold declined more and more slowly and it took longer time to reach a stable value. An additional fact was that a phenomenon like the backward sensitization was found in MT's data.

Discussion and Conclusion

Previous studies have shown that the magnitude of the masking effect associated with the sudden increase in the MS luminance is influenced by the degree of the change in luminance, that is, the larger the change is, the greater the masking peak is (Baker, 1949; Battersby & Wagman, 1959; Boynton, Bush & Enoch, 1954; Crawford, 1947; Sperling, 1965). Present results showed that a similar reduction in the masking effect could be obtained by the change in the rise time of MS, that is, the peak of the masking function was lowered as the rise time became longer. This means that the same process may be brought about in the visual system not only by lessening the change in luminance but also by lengthening the rise time of MS.

Such an observation is the case when the latency of the masking peak is examined. With the usual stepwise increment masking, the peak latency of the masking function is longer for the small change in the MS luminance than for the larger one (Boynton, Bush & Enoch, 1954; Boynton & Siegfried, 1962). This was comparable with the present results revealing that the longer the rise time of MS was, the longer the peak latency was, although this was not the case with the HI's data. To be noted here, however, is the fact that the extent of the variation in the peak latency is larger when the rise time is varied than when the luminance is varied.

The results of Experiment II can be also compared with the masking by the usual stepwise decrement MS. The amount of the small rise in the TF threshold at the sudden decrement of MS was not so largely influenced by the degree of the change in luminance, at least, in the photopic level of luminance (Baker, Doran & Miller, 1959). This was consistent with the present results showing that, under the employed conditions of decay time, the variation of the decay time of MS did not influence the magnitude of the masking peak. Present results on the peak latency of the masking by the decrement MS, however, appear to be inconsistent with the previous studies. Although the masking peak was always at the beginning of the stepwise decrement (Baker, 1953; Baker, Doran & Miller, 1959), which was certainly the case under 0 msec decay time condition in this study, present data showed that the temporal position of the peak moved forward in time when the decay time was replaced by longer one. But this result could be inferred from the results of Experiment I showing that the latency variation was large when the rise time of MS was varied.

Masking effects obtained by means of the increment threshold technique as in this study have been often regarded as the indirect on- or off-response of the visual system to MS (Boynton, 1958; Boynton & Kandel, 1957: Ikeda & Boynton, 1965). According to this view, the present results show that the on-response of the human visual system may be more amenable to the change in luminance and the mode of the luminance change than the off-response. In other words, the on-response is soon diminished, whereas the off-response is obstinately present when the degree of the luminance change is much reduced or when the decay time of the stimulus is much prolonged, at least, in the photopic level of luminance.

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