Visual Responses to Brief Flashes of Different Temporal Stimulus Wave Forms

VISUAL RESPONSES TO BRIEF FLASHES OF DIFFERENT TEMPORAL STIMULUS WAVE FORMS

By

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With the increment threshold technique the masking effects were measured for the three brief flashes which were equal in the total amount of energy change but differed in the distribution of luminance in time; rectangular wave, positive ramp sawtooth wave and negative ramp sawtooth wave. Results from two subjects were the following three: masking functions of the three temporal stimulus wave forms were (1) nearly identical in the shape, (2) nearly equal in the peak height although that of the rectangular wave tended to be slightly high, and (3) different in the temporal position of the peak, that is, the peak of the positive ramp swatooth wave was delayed by 10–15 msec with respect to the peak of the other two waves both of which had the same position. From these results it was discussed that under the present conditions the visual system responded to the amount of energy change alone inrrespective of its distribution in time, and that the hypothesis based on the temporal element theory was inapplicable to the present results.

Problem

It is well recognized that within a certain limited range of durations the visual effects such as threshold determinations can be achieved by the reciprocal manipulation of luminance and duration of the flash, that is, they can be determined when the product of luminance and duration is constant (stated mathematically, $L \times t = C$, where L is luminance, t is duration of the flash, and C is a constant.) This reciprocal relationship is known as the Bloch's law. This term of $L \times t$ is a total amount of light energy of a flash provided that the retinal area stimulated is constant and therefore the Bloch's law may be restated in the following way; within a certain limited range of durations the visual effects are determined by a total amount of light energy, or the visual system responds equal to the stimuli of equal energy.

In this statement it becomes a problem whether or not the response of the visual system may be influenced by the luminance distribution of the stimulus in time (the temporal stimulus wave form) because there are many stimuli which are equal in the total amount of energy but differ in the luminance distribution. For the various levels of visual responses it is necessary to examine the effect of this variable.

As for the absolute threshold for seeing flashes Long (1951) examined this effect. Using several stimuli of different temporal distribution of the luminance he obtained the result showing that within a certain critical duration the changes in the wave form of the light flash did not affect the total amount of energy required to produce a threshold response and concluded that the total amount of energy was the sole determiner of thresholds. With respect to the other visual responses the effects of the temporal stimulus wave form have not been investigated.

With the increment threshold technique Boynton & Siegfried (1962) measured the masking effects of two brief flashes, both in a critical duration, which differed in luminance and duration but were equal in total energy, obtaining the result showing that the two masking functions were essentially identical in their form and differed only in latency.

The masking function seems to be an appropriate index which reflects the overall response of the visual system to the stimulus and it is interesting to examine whether it is the case or not with this response index to the above mentioned problem. The aim of the present study is, therefore, to obtain masking functions of the several brief stimuli that differ in the temporal distribution of luminance but are equal in the total amount of energy change. If the visual response of this sort is determined solely by the total amount of energy, then, as shown in the result of Boynton & Siegfried, masking functions will be identical in form and a certain phase shift among them will be found.

Method

Apparatus

The apparatus was shown schematically in Fig. 1. The channel A generated the adapting background and the masking stimulus and presented them to the subject, while the channel B the test flash for measuring the luminance increment threshold at several temporal points before, during and after the masking stimulus.

In order to generate the temporal stimulus wave form of the masking stimulus, a similar method to that described elsewhere (Maruyama & Matsumura, 1974) was employed, namely, the method of frequency-modulation of glow train. A trigger pulse, delayed by 100msec, drove a function generator which generated a single voltage wave set in advance. This wave rose from OV to +4V. By feeding this voltage into the VCF(voltage controlled frequency) circuit, a 200Hz rectangular wave was frequency-modulated in correspondence with the voltage change. The range of modulation was from 200Hz(OV) to 1000Hz (+4V). This modulated rectangular wave triggered a pulse generator to get a modulated pulse train of which the pulse duration was 0.35msec with the voltage of +50V. After amplified through a power amplifier up to +115V, this frequency-modulated pulse train was fed into the glow modulator tube (R1131C) from which the frequency-modulated glow train was produced. As the frequency of the glow train was well beyond CFF, change in brightness was identical to the input voltage wave form generated from the function generator according to the Talbot-Plateau's law. The changes in brightness began from the mean brightness of a 200Hz glow train because the 200Hz pulse train formed the base on which the frequency modulation was made, and this mean brightness formd the adapting background when the masking stimulus was absent.

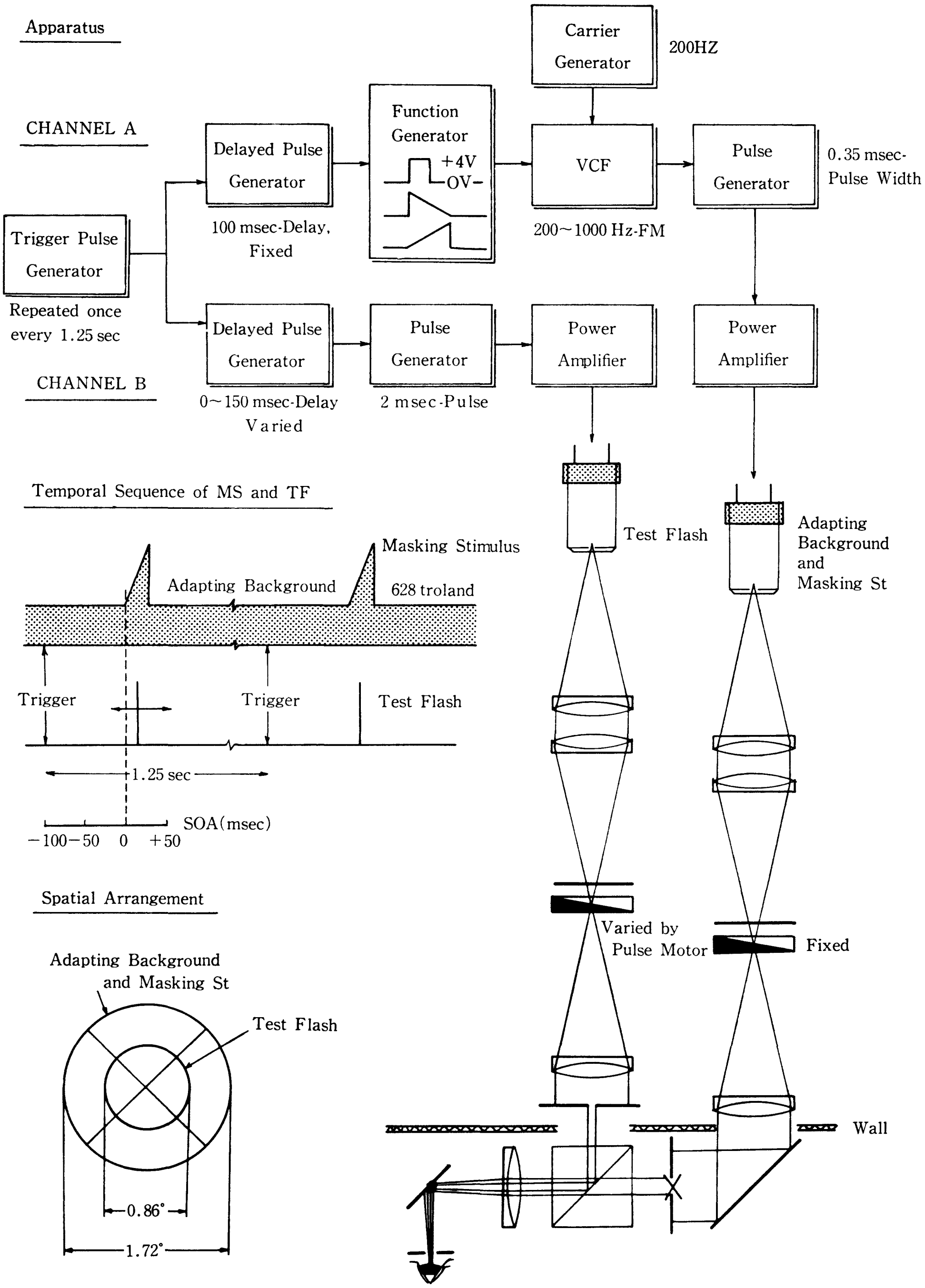

Fig. 1 Blockdiagram of the apparatus, schematic representation of the temporal sequence of MS and TF, and the appearance of MS and TF to the subject.

On the other hand the pulse which generated the masking stimulus was delayed by 0–150msec and triggered another pulse generator, which then produced a single rectangular pulse of which the width was 2msec with the voltage of +50V. After amplified by another power amplifier up to +115V, this pulse flowed into another glow modulator tube and thus the test flash was obtained. Duration of the test flash was 2msec and this was calibrated before every experimental session.

The SOA between the onset of the masking stimulus and the onset of the test flash was controlled by the combination of the two delayed pulse generators and always checked by the time counter and the dual beam oscilloscope.

The light fluxes emanated from two glow modulator tubes were provided to the subject's left eye through the dual Maxwellian view optical system. Each beam was collimated by a lens, focused by another lens upon an optical neutral density wedge, and again collimated by a lens. Thereafter one of two beams (channel A), after passing through an opening of the wall, was deflected 90° by a mirror, restricted by a field stop, then produced an image on an artificial pupil of 2mm in diameter. Another beam (channel B) was restricted by a field stop, passed through another opening of the wall, deflected 90° by a half-silvered beam splitter prism and then threw another image superimposed on the former one at the artificial pupil. In each beam the field stop was located at focal length from the imaging lens and this guaranteed a sharp image on the retina at apparent infinity.

When both tubes were operating at the same time, the subject saw a circular adapting background or a masking stimulus subtending a visual angle of 1.72° and in the center of it a circular spot of the test flash, 0.86°. The central fixation was employed on these targets and this was secured by locating a pair of cross-hairs on the field stop in the channel A.

The luminance of the adapting background was kept constant throughout the experiment and the luminance of the masking stimulus varied upward from this constant level of luminance. The luminance of the test flash was changed with the circular neutral density wedge which was automatically driven by a pulse motor.

Calibrations of these luminances were made by the binocular matching in which the subject observed the field of Maxwellian view with one eye and the diffuse surface of the frosted grass screen with the other eye, the luminance of the latter being measured with a standardized photometer.

Procedure

The masking stimuli examined in the present study were the following three temporal wave forms: the rectangular wave, the positive ramp sawtooth wave and the negative ramp sawtooth wave. Stimulus exposure time at the base was 15 msec in case of the rectangular wave and 30 msec in case of sawtooth waves. They all rose from the constant luminance level of 628 trolands (200 nit) up to the constant peak luminance of 3140 trolands (1000 nit). Thus they were equal in their total amount of energy change and different only in the temporal distribution of luminance. In the preliminary experiment in which the total of seven subjects participated, luminance difference thresholds of these stimuli were measured at the same luminance level, and it was confimred that the nearly equal energy change was required for the determination of the threshold of each wave. This result was considered as the prerequisite for the present experiment.

Luminance increment thresholds of the test flash were measured at various temporal points before, during and after the masking stimulus. The SOA between two stimuli ranged from –100 msec to +50 msec. Negative values indicate the conditions of the test flash preceeding to the masking stimulus in time. Total of 14 SOAs were included in this range.

At a given SOA the sequence of the masking stimulus and test flash was repeated once every 1.25 sec. While subjects were observing this sequence, the luminance of the test flash was increased or decreased. This change in luminance was performed step by step with a pulse motor and subjects stopped this motor at the appearance or the disappearance of the test flash, respectively.

One session consisted of three blocks in which the masking functions of three temporal stimulus wave forms were measured. Within any one block the thresholds of the test flash were obtained for all SOAs and two thresholds, ascending and descending, were determined at each SOA. In addition to these threshold measurements, thresholds of the test flash without the masking stimulus (resting thresholds) were obtained before and after each block. The total of six sessions were administered to counterbalance the order of presentation of the wave forms and the order of SOAs. SOAs were presented in the order from negative to positive in one half of sessions and in the reverse order in the other half of sessions.

Before the experiment began subjects were dark-adapted for 10 minutes and then light-adapted to the adapting background for about 5 minutes.

An undergraduate and the present author served as subjects and both were trained well for this study.

Results

Data from the two subjects were presented in Fig. 2, where luminance increment thresholds for the test flash superimposed on the masking stimulus were plotted as a function of SOA between the masking stimulus and the test flash for each temporal stimulus wave form. Each point on a curve is the average of 12 determinations of the thresholds which were obtained in a total of six sessions. Each line on a point indicates two SDs of these 12 determinations. Resting thresholds were shown on the right side of each graph.

Results were redrawn in Fig. 3, where masking functions of three temporal stimulus wave forms were overlapped.

From an inspection of Fig. 2 and 3, the following facts should be noted:

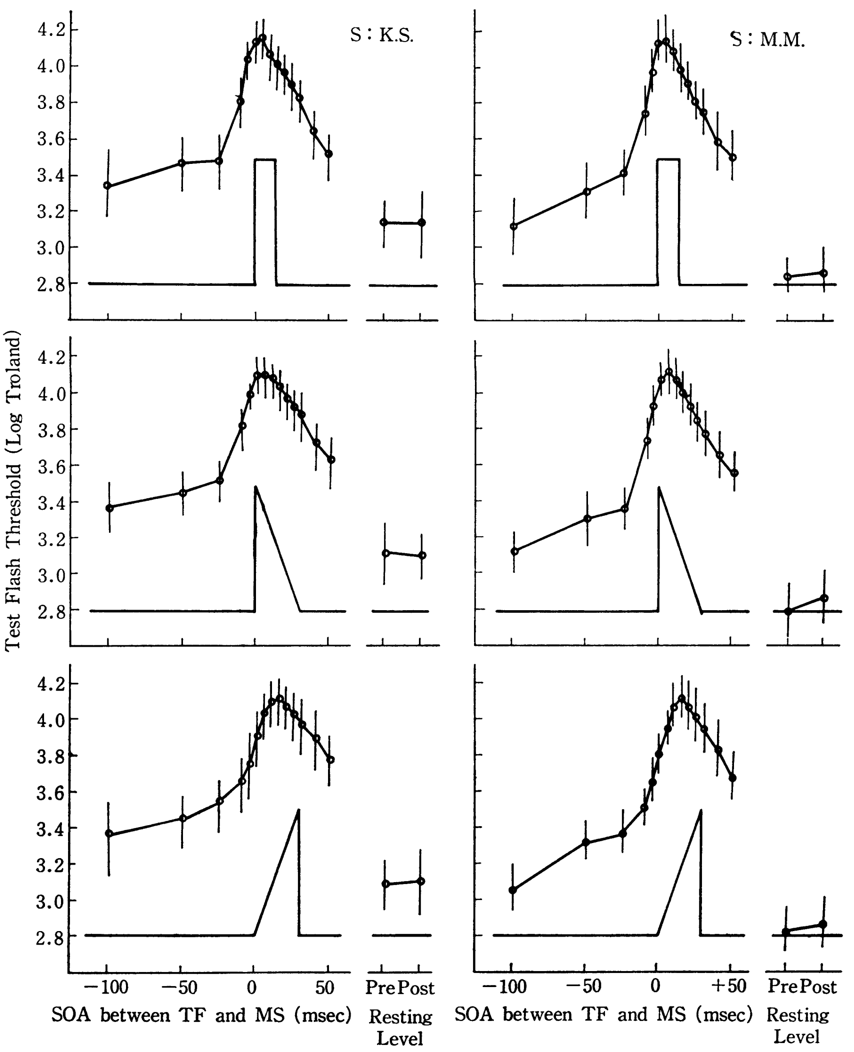

Fig. 2 Masking functions of three temporal stimulus wave forms. Data from two subjects.

(1) Masking functions of the three temporal stimulus wave forms were nearly identical in the form of the function.

(2) They were nearly equal in the peak height of the functions where the masking effect was strongest although the peak of the rectangular wave tended to be slightly high.

(3) They, however, differed in the temporal position of the peak of the functions. The peaks of the rectangular wave and of the negative ramp sawtooth wave were nearly identical and located at the SOA between 0 msec and +5 msec. The peak of the

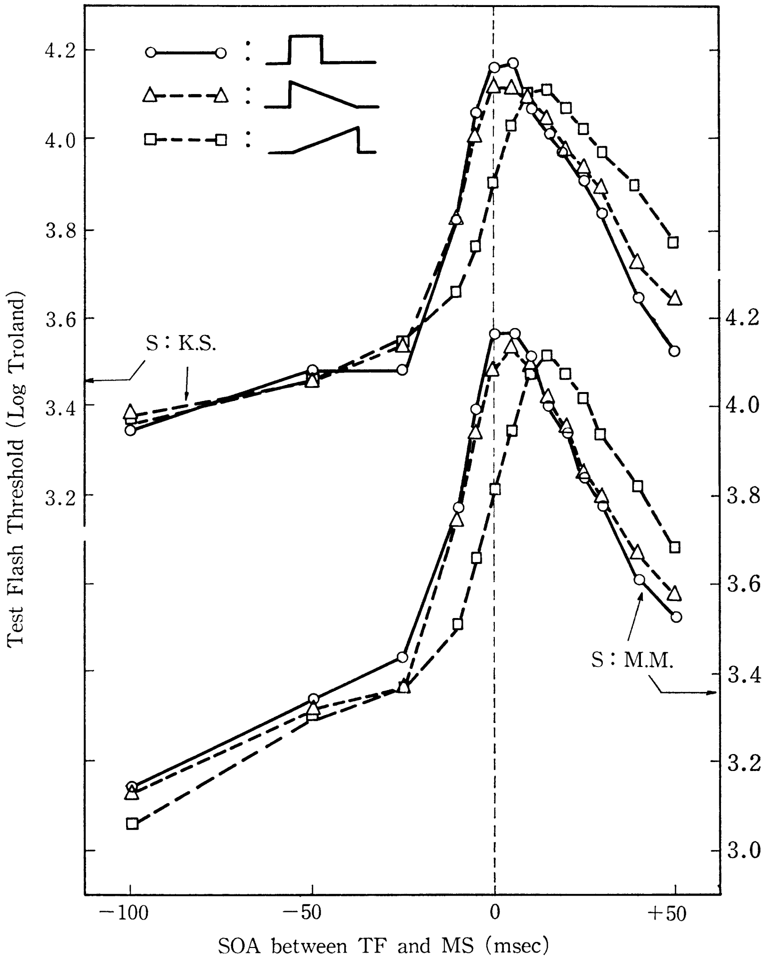

Fig. 3 Overlapped representation of three masking functions.

positive ramp sawtooth wave was delayed by +10–15msec in comparison with the peaks of the other two wave forms and positioned at the SOA of +15msec.

Discussion and Conclusion

Present results confirmed the essential finding of Boynton & Siegfried (1962). Visual responses, measured with the increment threshold technique, to the stimuli differing in the temporal stimulus wave forms but equal in the total amount of energy change were identical in the shape as well as in the magnitude. This implies that under certain limited conditions the visual system responds to energy (change) alone irrespective of its distribution in time, as was referred to in the recent reviews (Boynton, 1961; 1972).

The result of the difference in the peak latency of the responses found in the present study rejects one interpretation of this sort of experimental results. In order to account for their result obtained with the usual rectangular brief stimuli, Boynton & Siegfried (1962) proposed one hypothesis which assumed that the gross response to a stimulus was the sum of the elemental responses to each elemental component of the stimulus. This hypothesis, advanced by Johnson (1958) and Blackwell (1963) independently, seems to be inapplicable to the present results. According to this hypothesis the peak latency of the negative ramp sawtooth wave must be shorter than that of the rectangular wave whereas the fact is that the peak latencies of the two waves are nearly equal. A more acceptable explanation would be necessary although it could not be found in the present study.

In order to account for the relatively large delay of the peak latency found in the masking function of the positive ramp sawtooth wave, it is necessary to conduct further experiments which control systematically the onset slope of the stimulus.

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(Received August 25, 1975)