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STIMULUS WAVE FORM AND MODULATION SENSITIVITY CURVE

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The characteristics of flicker detection was investigated at the lower frequencies by measuring the modulation sensitivity curve with five stimulus wave forms.

A method of "frequency modulation of glow train" was used to vary the wave form. A test patch had a visual angle of 2° with a mean luminance of 4.40 trol. and was surrounded by dark field. At several points covering lower frequency region, the threshold modulation amplitudes (*m*) were measured by asking several *S*s to judge the disappearance of successive contrast.

A distinctive effect of wave form difference appeared in the amplitude-frequency curves. Above 10Hz, the results were in good agreement with the reducibility hypothesis (de Lange, Kelly). Below 10Hz, the amplitude sensitivity for the rectangular and two saw-tooth waves was higher than that for the sinusoidal and triangular waves. At 2Hz, the positive ramp saw-tooth wave was equivalent in threshold sensitivity to the rectangular wave which was the highest all over the frequency range covered in this study. There was little difference between the sinusoidal and triangular wave stimuli. That the negative ramp saw-tooth wave is lower in sensitivity than positive ramp saw-tooth, was confirmed by further experiment in which a statistically reliable difference was found between them employing 8 untrained *S*s.

The mediating processes for these wave form effects found at the lower frequency region were discussed in connection with on- and off-responses of the visual system.

PROBLEM

Maruyama (1976) has shown that variation of wave form in flicker stimulus has a very remarkable effect on flicker thresholds at frequencies greater than about 10Hz, and confirmed that these CFFs can be predicted from the amplitude of fundamental Fourier component of the wave form as was presented in Ives' theory.

According to the modulation transfer function obtained by Kelly (1961), the validity of the Ives' theory is easily explained at the flicker thresholds of higher frequencies. At lower frequencies below about 10Hz, however, it is inferred that the flicker thresholds would not be determined solely by the fundamental component independently of the wave form, since the Kelly's function suggests some contribution of higher harmonics to threshold determination. Consequently, at the lower frequencies, stimulus wave forms would affect CFF in a different manner from Maruyama's high-frequency thresholds.

De Lange (1954), who explored conciderably wide frequency range on the effect of wave forms on CFF, measured CFF for only one kind of wave form (i.e., trapezoidal one) at the low frequency region of below 8Hz partly owing to his apparatus limitations.

The purpose of this study is to examine the effect of wave form on flicker threshold at the lower frequency region by obtaining the modulation sensitivity curve for each wave form.

Method

The "frequency modulation of glow train" was used to vary the wave form of flicker stimulus. The details of this method were described elsewhere (Maruyama, 1976).

Four wave forms of rectangle, sine, triangle, and positive ramp saw-tooth were employed in Exp. 1. In Exp. 2 the positive and negative saw-tooth waves were compared with each other and with the rectangular wave added as a control.

A light beam from the glow modulator tube (R1131C) was projected on the surface of frosted glass and the back of this glass was surrounded by dark field thus making a round test patch of a visual angle of 2°. The patch was observed through an artificial pupil of 2 mm in diameter by the right eye of the *S*. Mean luminance was fixed at 4.40 trol.

To obtain modulation sensitivity curve, the modulation amplitude at a given frequency was reduced till the successive contrast between the adjacent flashes disappeared in the same way as in CFF measurement. For each amplitude threshold, more than 5 measurements were taken at each frequency using the method of adjustment.

Three *S*s of KM, MK, and TA for Exp. 1, and four *S*s (KM, MK, TA, and TK) in Exp. 2 were employed respectively. KM was the author himself and the others were undergraduates majoring in psychology. MK was a female student. The experiments were conducted from May till August, 1973.

Results and Discussion

The modulation sensitivity curves obtained in Exp. 1 are shown in Figs. 1, 2, and 3 for each of the three *S*s respectively. In these Figures, the modulation ratios (m) at threshold were plotted as a function of frequency of the flicker stimulus. Each point was based on more than 5 measurements.

Figs. 4, 5, and 6 (Effective modulation sensitivity cruves) illustrate the same results with the ordinate values substituted for modulation ratios of the fundamental sinusoidal component at threshold (m_1). This was done by multiplying the ordinate values shown in Figs. 1 to 3 by 1.27 for the rectangular wave, 1.0 for the sinusoidal, 0.81 for the triangular, and 0.64 for the saw-tooth, respectively.
*SD*s for several m's are shown for the sinusoidal wave data in Fig. 4. The *SD*s for other data of this *S* did not differ much. The same can be true of the other two *S*s' *SD*s.

The data of the four *S*s obtained in Exp. 2 are shown in Figs. 7 and 8 in the same manner as those in Exp. 1.

Main results that can be read from these Figures are summarized as follows:

(1) Figs. 1 to 3 show that the difference in wave forms affected the modulation

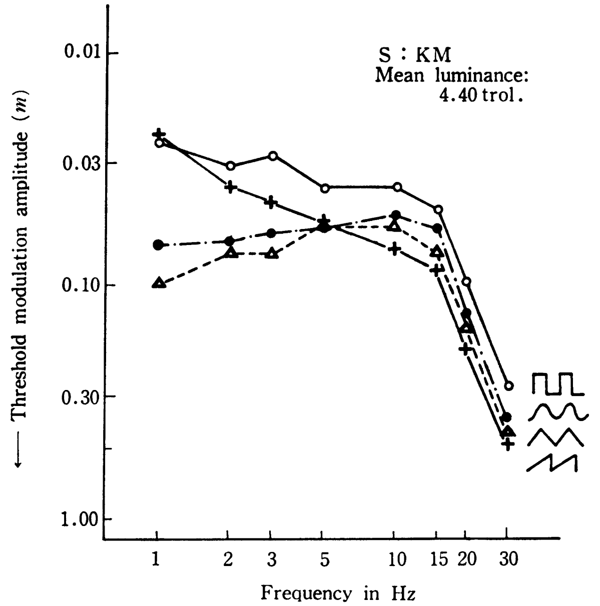

Fig. 1. Modulation sensitivity curves for each of 4 wave form stimuli (Data of KM).

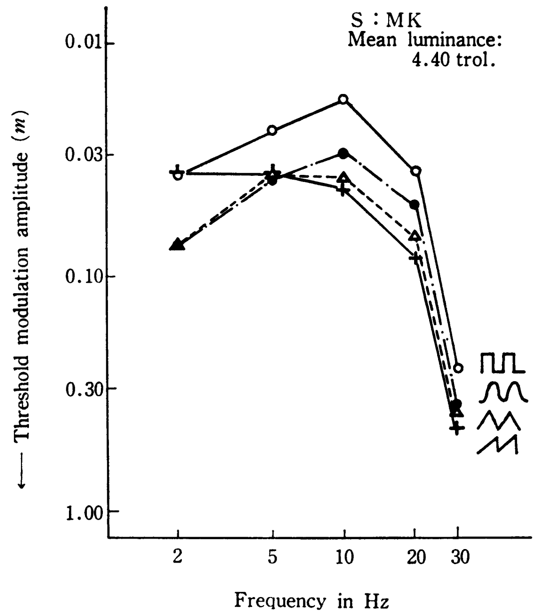

Fig. 2. Modulation sensitivity curves for each of 4 wave form stimuli (Data of MK).

sensitivity markedly. The manner of this effect seems to be different whether flicker frequency exceeds 10Hz or not.

(2) Above 10Hz, as shown in Figs. 4, 5, and 6, the threshold amplitudes of fundamental component were approximately equivalent for every wave form used.

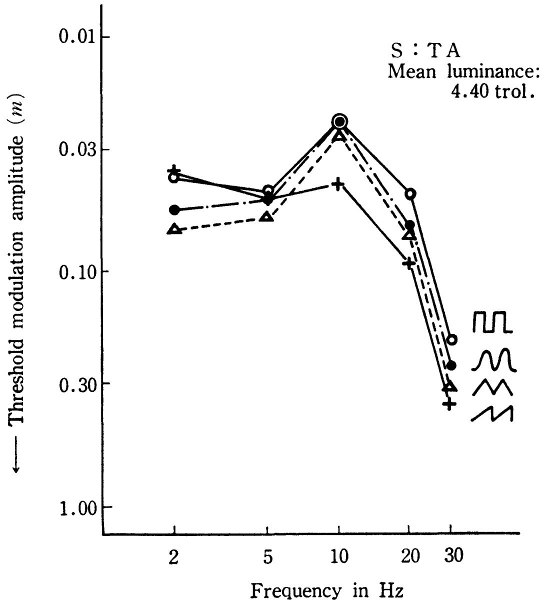

Fig. 3. Modulation sensitivity curves for each of 4 wave form stimuli (Data of TA).

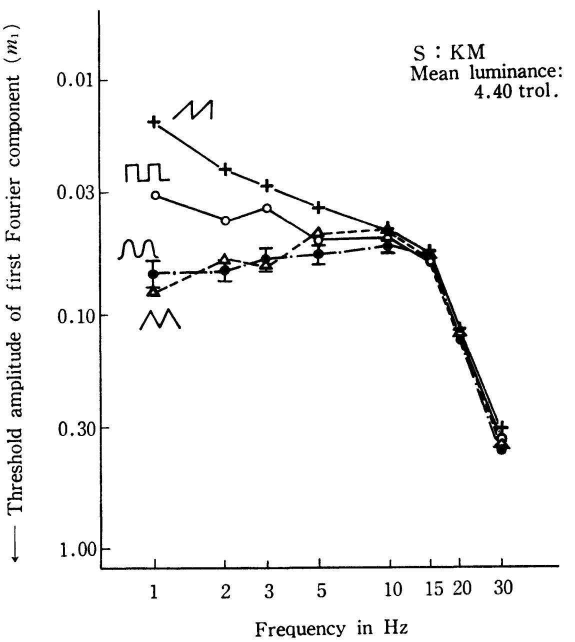

Fig. 4. Effective modulation sensitivity curves for each of 4 wave form stimuli (Data of KM). Ordinate: Threshold modulation amplitude of first Fourier component in each wave form (effective modulation ratio, m_1).

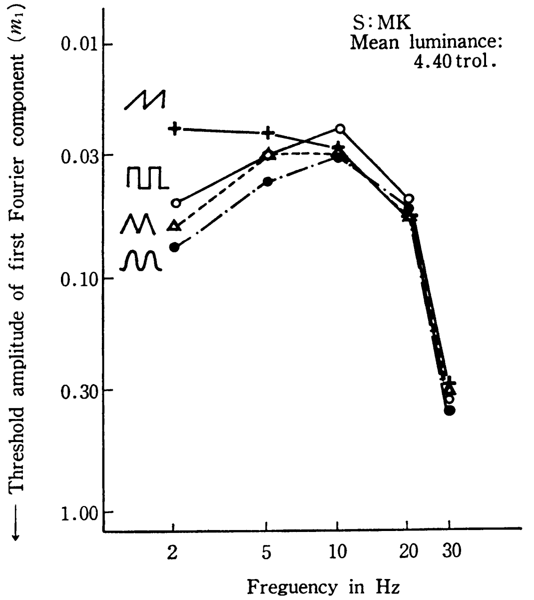

Fig. 5. Effective modulation sensitivity curves for each of 4 wave form stimuli (Data of MK).

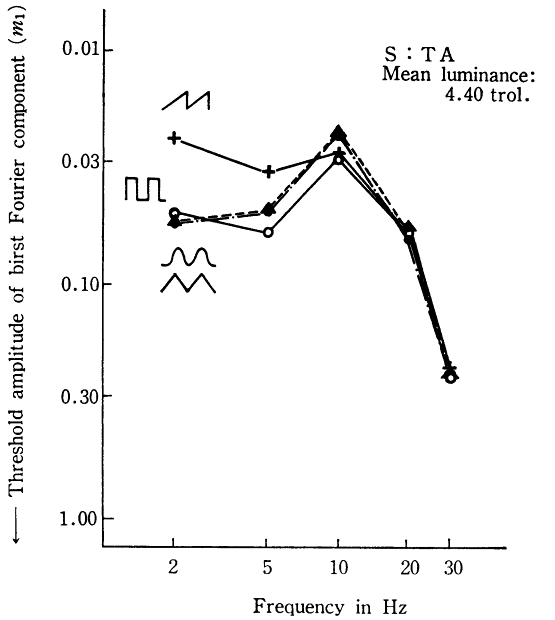

Fig. 6. Effective modulation sensitivity curves for each of 4 wave form stimuli (Data of TA).

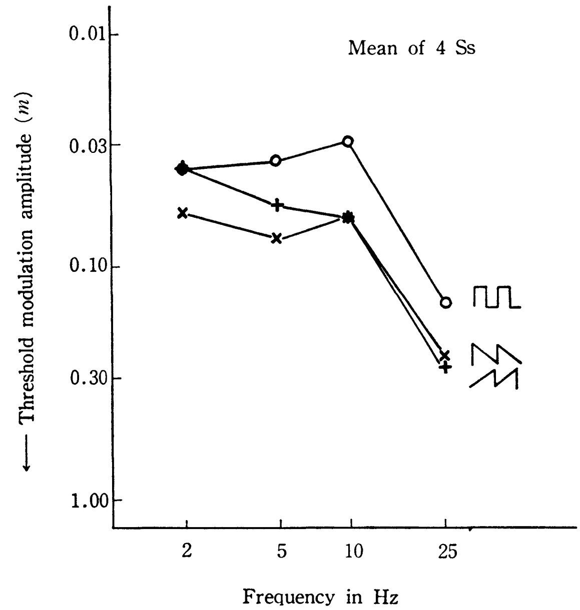

Fig. 7. Modulation sensitivity curves for each of 3 wave form stimuli (mean of 4 *S*s).

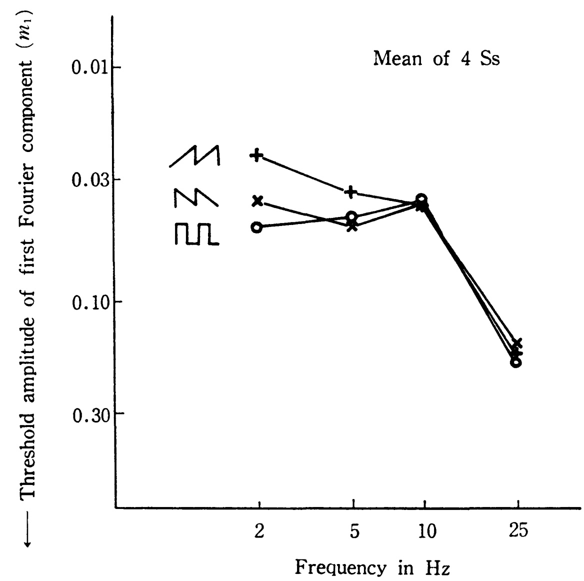

Fig. 8. Effective modulation sensitivity curves for each of 3 wave form stimuli (mean of 4 *S*s).

This is just another confirmation of de Lange's results. Thus it is shown that the "reducibility hypothesis" could be applied to the present results showing that higher-frequency flicker thresholds for a given adaptation level can be predicted from the amplitude of the first Fourier component of the wave form.

(3) Below 10Hz, as inferred at the outset, the linear system analysis cannot explain the obtained results, though it is applciable to the higher frequency region. As shown in Figs. 1 to 3 at the lower frequency region, the sensitivity of flicker detection to the rectangular and saw-tooth waves was higher than that to the sinsuoidal and triangular waves. The saw-tooth wave, which gave the least sensitive threshold at the higher frequency region, enhanced its sensitivity to be equivalent to sinusoidal and triangular waves at 5Hz, and excelled them at 2Hz where it was comparable to the rectangular wave except for KM for whom the equivalence held at 1Hz.

There was little difference in m between the sinusoidal and rectangular waves at the lower frequency region. Difference in m between these two waves and the rectangular or the saw-tooth wave was considerable at 2Hz.

(4) Figs. 7 and 8 which summarized the results of Exp. 2 show the same trend as was reported above. At 2Hz, the positive ramp saw-tooth wave was equivalent in sensitivity to the rectangular wave, and excelled the negative ramp saw-tooth. At the higher frequency region of 10Hz or above, these two saw-tooth waves showed no difference, and as shown in Fig. 8, the threshold amplitude was determined almost exclusively by the first Fourier component of each wave form.

(5) The shape of modulation sensitivity cruves for each S was as a whole in good accordance with that provided by Kelly (1961).

A Further Investigation on the Effect of Two Saw-tooth Waves (Aihara's Data):

Takashi Aihara (相原隆志) obtained the threshold modulation amplitudes at 2Hz for both the positive and negative ramp saw-tooth waves as a part of his graduate experiment. There were 8 Ss, most of whom were untrained graduate students. The order of measurement between the two wave forms was counterbalanced among the Ss. The other conditions were identical with those adopted in Exp. 2. Table 1 shows the summarized means and SDs for each S and these across the Ss. A statistical test revealed a significant difference between the threshold amplitudes of the two waves at the 2 levels. Therefore, it may be concluded that the threshold sensitivity for flicker detection was higher when measured with the positive ramp wave than with the negative ramp. This conclusion supports the result of Exp. 2.

Table 1. Results of Aihara's experiment. Means and SDs of threshold amplitude (m) in 2 wave form stimuli at 2Hz.

Wave form	Subjects								Mean (SD)
	TA	YK	HO	KM	SO	IT	JI	SA	
Positive ramp saw-tooth	0.027 (0.004)	0.042 (0.009)	0.025 (0.010)	0.038 (0.008)	0.033 (0.006)	0.050 (0.004)	0.032 (0.014)	0.037 (0.009)	0.036 (0.0076)
Negative ramp saw-tooth	0.038 (0.004)	0.074 (0.014)	0.043 (0.011)	0.059 (0.005)	0.036 (0.015)	0.042 (0.008)	0.050 (0.007)	0.056 (0.007)	0.050 (0.0120)

The magnitude of difference in m between the two saw-tooth waves was 0.014 in Aihara's data and 0.021 in Exp. 2. This magnitude was approximately within the range of variance of a cluster of curves at 2Hz, which was reported in Kelly. He regarded it as due to measurement errors, and concluded that modulation transfer functions converged at a constant value. Anyway, the difference in m between the two kinds of saw-tooth was not remarkable, though it seemed to exist distinctively.

How should the differential effect of wave form in the lower frequency region, as suggested by the above mentioned three experiments, be explained? Principles of linear system analysis cannot deal with the lower frequency region where the visual system shows non-linear characteristics.

The present data seem to suggest that the flicker detection at the lower frequencies is mediated largely by the on- and/or off-responses in the visual system. One reason for this suggestion is that no difference was found in sensitivity for flicker detection between the sinusoidal and triangular waves, and that their sensitivity was lower than that of rectnagular and two saw-tooth waves. In contrast to gradual rise and decay slope in the sinusoidal and triangular waves, the rectangular and two saw-tooth waves have a steep rise and/or decay slope. If it is assumed that on- and off-responses that would mediate the flicker detection depend on the sharpness of stimulus onset or offset respectively, then it follows that flicker sensitivity would be higher with the rectangular and two saw-tooth waves than with the sinusoidal and triangular, since the former would keep sharpness at the onset and/or offset at the point where the latter lose their sharpness as the modulation amplitude is decreased.

This assumption, however, must be further modified if it is applied to the results showing that both the rectangular and the positive ramp saw-tooth waves were higher in sensitivity than the negative ramp saw-tooth with no difference between the former two waves, as this seems to imply that threshold modulation amplitude was mainly determined by off-response. This hypothesis concerning the relationship between the stimulus wave form and on- and off- responses of the visual system including the just mentioned possibility awaits further examination.

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