Stimulus Wave Form and CFF

STIMULUS WAVE FORM AND CFF

By

KINYA MARUYAMA (丸山欣哉)

(Department of Psychology, Tohoku University, Sendai)

By means of frequency modulation of glow pulse train, regularly repeating stimuli having different wave forms were produced and CFF for these stimuli were measured. These flickering stimuli were presented at the center of dark visual field. A test patch subtending a visual angle of 2° had mean luminances of 0.12, 0.42, and 4.40 trol. with constant modulation ratio (*m*) of 0.29.

CFF values were quite stable both between- and within-subjects. A clear-cut effect of wave forms was obtained with the highest CFF for rectangular wave form, next highest for sinusoidal followed by triangular and saw-tooth waves under every luminance condition.

Problem

Ives (1922) investigated CFF for the regularly repeating, time-varying stimuli with various wave forms of rectangular, saw-tooth, triangular, and sinusoidal variations at a scotopic luminance level with the blue light. He found that CFF was highest for the rectangular wave and lowest for the saw-tooth wave, and that it differed little between two sawtooth waves which had either positive or negative ramps respectively. He proposed that these results could be accurately predicted from the hypothesis that fusion frequency was determined in most instances by the amplitude ratio of the Fourier fundamental component to the mean luminance, whatever wave forms were used.

Luckiesh (1914) found a similar result, using rectangular, saw-tooth, and clipped saw-tooth waves. Brown (1965) has pointed out that the same conclusion as the Ives' can be drawn from the results of an experiment conducted by Goldman, König, and Mäder (1946), in which an intermittently illuminated, moving stripe was employed.

On the other hand, however, Brown has cited a study by Ronchi & Bittini (1957) who found in apparent contradiction to the above findings that for a given frequency, fusion occurred at a lower luminance for a saw-tooth stimulus than for a stimulus made up of rectangular pulses. Furthermore, Kennelly and Whiting (1907), as cited by Luckiesh (1914), showed that CFF does not appreciably depend on the wave forms of flicker stimuli used.

De Lange and Kelly sought to analyze the response characteristics of visual system to the time-dependent stimuli from the viewpoint of linear system analysis in electronics. De Lange (1954) measured fusion thresholds for four stimulus wave forms under three retinal illuminance levels. As is usually the case in electric filter technics, his obtained results were plotted as attenuation characteristics curves of the visual system, in which the amplitude of fundamental components for four waves was adopted as modulation amplitude at fusion. It turned out that the obtained curve for each wave form was superimposable on each other under all the 3 adaptation levels used. Thus, Ives' theory was confirmed again by the study of de Lange.

The CFF for a given wave form stimulus is related solely to the characteristics of first Fourier component and independent of higher harmonics and it is also predictable from the Kelly's temporal transfer function, although its application is restricted within a range of higher frequency.

The purpose of this study is to present further evidence for these points using the same stimulus wave forms as were used by Ives. Two methodological improvements were added: (1) A more exact technique than that adopted by the former researchers was devised to generate the wave forms. Both Ives and Luckiesh used a sector and de Lange used a rotary disc. (2) These three authors obtained data only from one subject, namely, the authors themsevles, but in this study several subjects were employed to remove individual difference factors.

Method

Frequency modulation of glow train: As a method for generating the wave forms, a frequency modulation technique of glow train was devised (Maruyama, 1973; Maruyama & Matsumura, 1974). It was based on the three components: (1) Talbot-Plateau's law, (2) frequency modulation, (3) glow modulator tube. It is well known that an objectively intermittent light will be perceived as one of fused brightness if flickering is at amply high frequency. According to the Talbot-Plateau's law the brightness of fused stimulus is apparently equal to a continuous stimulus having time-averaged luminance of the flicker stimulus. Thus by delivering frequency modulation to the pulse train that was perceived as fused or continuous light, a brightness change having a given wave form could be obtained. The block diagram in Fig. 1 shows the way of generating flickering stimuli by the method. By feeding a given wave output (peak to peak: ± 1volt) from a function generator which could generate five different waves to a VCF (voltage controlled frequency) circuit, 700Hz square wave pulses from a carrier generator was modulated within the range of 500Hz to 900Hz. These modulated pulses triggered a train of pulses of 0.05msec width, which were then amplified and fed to a glow modulator tube (R1131C). Time-dependent brightness changes obtained in this way were perceptibly identical to the output wave form of the function generator. Wave forms and pulse trains were continuously monitored by an oscilloscope and a frequency counter.

One virtue of the method was that it could manipulate easily and accurately such parameters as wave form, frequency, average luminance, amplitude, and phase without causing such troubles as color shift. On the other hand, it had a disadvantage in that it could not give the modulation ratio (m) of 1.00 with the result showing that a test flush cannot rise from zero illuminance background, since frequency modulation must

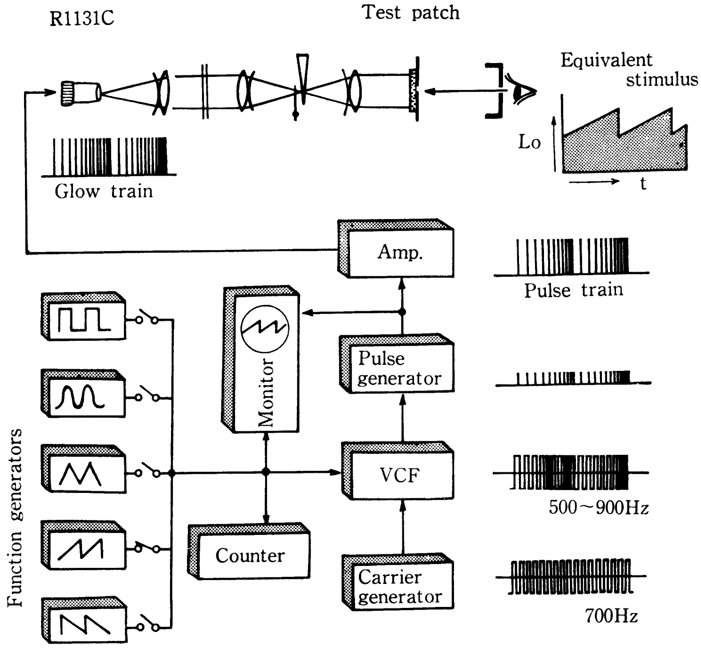

Fig. 1. Block diagram of apparatus.

have been performed on the carrier frequency. Maximal modulation available was 0.82, in this apparatus.

Procedure: The stimulus wave forms used were rectangular, sinusoidal, triangular, and saw-tooth waves of either positive or negative ramp. They were much the same with those used by Ives. Modulation ratio (m) was 0.29 for all the stimuli.

The test stimulus which subtended a visual angle of 2° was a round frosted glass placed at the center of dark field and observed by the *S*s' night eye through an artificial pupil of 2 mm diameter. As the arrangement of the optical system shown in Fig. 1 indicated, the beam emitted by glow tube passed through a ND filter and optical wedge to illuminate the back of the test patch. Mean luminance of the test field was set to be 0.12, 0.42, and 4.40 trol. by adjusting the filters.

A method of adjustment was employed to obtain CFF values. *S*s were allowed to adjust frequency of the flickering test patch in the direction of fusion to their satisfaction. Each *S* gave at least four thresholds for each condition, which was averaged to obtain a threshold for the condition.

Two experiments were carried out. In Exp. 1, rectangular, sinusoidal, triangular, and positive ramp saw-tooth waves were used, each of which was observed under three luminance levels. Five male undergraduate students served as *S*s. All of them majored in psychology. In Exp. 2, three wave forms, i.e., rectangule, positive ramp swa-tooth, and negative ramp saw-tooth were used under three luminance conditions.

Under 0.12 trol. condition, four *S*s participated in the experiment, whereas under 0.42 and 4.40 trol. conditions, seven *S*s were used. Of these seven *S*s, KO was a female student. To complete the whole session it took about one hour for each *S* both for Exps. 1 and 2. The experiments were conducted from December 1972 till May 1973.

Results and Discussion

The *S*s unanimously reported that it was rectangular stimulus under the highest mean luminance that was easiest to determine the CFF, while saw-tooth waves under the lowest luminance was the hardest. This was because in case of rectangular wave it gave a distinctive impression of flickering at suprathreshold frequency which attenuated abruptly approaching fusion threshold.

The results of Exps. 1 and 2 are shown in Tables 1 and 2 respectively. In these Tables means (upper row) and ranges (lower row) for each wave form were shown in Hz for each *S*. The range was frequency difference between maximum and minimum

Table 1. Results of 5 *S*s in Exp. 1. Mean CFFs (upper row) and ranges (lower row in small figures) for 3 mean luminance levels of test patch in 4 wave forms are shown in Hz. The figures of column next to the rightmost Ives' values are the means across *S*s with their ranges and *SD*s: ( ).

Wave form	Mean luminance in trol.	Subjects					Mean	Ives' value
		MM	NS	HH	KM_i	KM		
Rectangle	0.12	13.9 0.8	13.8 0.4	14.7 0.7	14.2 1.7	14.8 1.2	14.3 1.0(0.41)	14.1
	0.42	17.9 1.3	19.6 0.9	22.6 3.7	17.8 1.0	18.4 0.9	19.3 4.8(1.79)	19.4
	4.40	29.6 0.8	30.8 3.3	32.9 2.5	28.6 2.0	30.1 1.3	30.4 4.3(1.44)	30.8
Sine	0.12	12.2 1.1	13.3 1.0	14.0 0.8	13.9 1.1	13.1 0.9	13.3 1.8(0.65)	13.3
	0.42	16.2 1.5	19.0 2.6	21.4 2.4	17.0 1.2	18.0 0.6	18.3 5.2(1.80)	18.3
	4.40	28.2 1.3	29.8 1.5	32.1 1.2	27.0 2.2	28.5 2.1	29.1 5.1(1.74)	29.1
Triangle	0.12	11.7 0.7	12.1 0.4	13.1 1.8	12.3 1.8	12.3 0.5	12.3 1.4(0.46)	12.5
	0.42	15.7 0.3	16.8 0.4	20.0 1.5	16.4 1.5	16.3 1.9	17.0 4.3(1.52)	17.2
	4.40	26.8 2.0	27.4 1.0	30.6 2.5	26.4 1.8	27.8 1.3	27.8 4.2(1.48)	27.4
Positive ramp saw-tooth	0.12	10.9 0.4	11.3 0.5	13.0 1.0	12.1 0.4	11.8 0.9	11.8 2.1(0.72)	11.7
	0.42	14.4 0.5	16.1 2.0	17.0 1.5	14.8 1.0	15.9 0.6	15.6 2.6(0.94)	16.1
	4.40	25.1 0.7	26.1 2.6	29.1 1.6	25.2 2.3	25.1 1.9	26.1 4.0(1.54)	25.6

Table 2. Results of Exp. 2. Upper row: mean CFFs; lower row in small figures: ranges; ( ): *SD*s.

Wave form	Mean luminance in trol.	Subjects							Mean	Ives' value
		YN_1	HK	TK	KM	YN_2	TY	KO		
Rectangle	0.12	13.6 2.1	11.9 0.3	13.8 3.2	14.3 0.8				13.4 2.4(0.91)	13.4
	0.42	18.7 0.9	15.6 1.1	15.4 0.7	18.5 0.1	17.8 1.8	18.6 0.1	18.3 0.7	17.6 3.3(1.29)	17.6
	4.40	29.4 1.7	25.8 3.1	25.9 1.4	29.5 2.8	32.0 1.6	30.3 2.3	30.7 3.3	29.1 6.2(2.14)	29.1
Positive ramp saw-tooth	0.12	9.7 0.7	8.8 0.6	11.2 2.0	12.0 1.3				10.4 3.2(1.21)	11.4
	0.42	13.4 1.6	11.4 0.5	13.8 1.1	16.4 0.8	14.2 0.9	14.4 0.3	13.9 1.4	13.9 5.0(1.36)	15.0
	4.40	24.6 4.4	21.2 1.3	23.7 0.2	26.6 1.0	26.6 0.9	25.9 4.9	25.6 1.9	24.9 5.4(1.79)	24.7
Negative ramp saw-tooth	0.12	10.4 1.4	9.1 0.9	11.5 2.4	12.2 0.8				10.8 3.1(1.17)	11.4
	0.42	14.3 1.7	12.2 0.5	14.6 0.6	15.3 0.7	13.3 0.4	15.2 0.6	14.1 1.1	14.1 3.1(1.05)	15.0
	4.40	25.3 4.1	20.8 1.3	22.8 3.8	26.7 2.8	27.0 4.3	26.5 2.7	25.9 2.0	25.0 6.2(2.16)	24.7

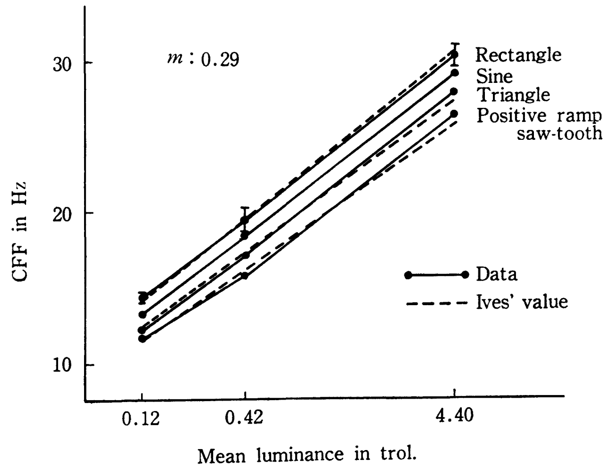

Fig. 2. Graphic representation of results of in Exp. 1. Mean CFF and Ives' value for each of 4 wave forms as a function of 3 mean luninance levels. *SD*s of 5 *S*s are shown in the data of rectangular wave form.

values of raw data. The figures of column next to the rightmost one are the mean of *S*s with their ranges and *SD*s in the parentheses. The mean CFF were plotted separately for Exps. 1 and 2 as a function of three mean luminance levels and shown in Figs. 2 and 3. The abscissae were both log scales.

The conclusions drawn from the Tables and Figures are summed up as follows:

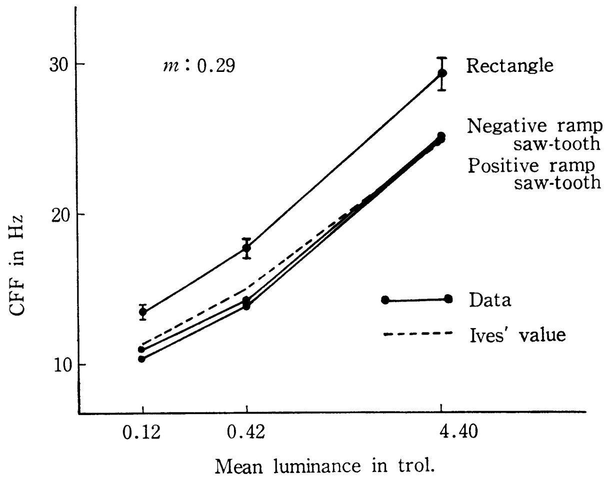

Fig. 3. Graphic representation of results in Exp. 2. Mean CFF and Ives' value for each of 3 wave forms as a function of 3 mean luminance levels. *SD*s are plotted in the data of rectangle.

(1) Within-subject variances as reflected in range values were very small (less than about 3% in terms of coefficient of variance). Thus each *S* gave quite stable CFF over the conditions. As was stated at the outset of this section, *S*s reported some differences in ease with which to determine CFF, but these differences was not large enough to be reflected in the variance of the measured values as assessed by coefficient of variation.

(2) Inter-subject variances were less than a few Hz, and their *SD*s were too small to be shown in the Figures.

(3) By comparing the curve for sinusoidal stimulus which represents the relationship between mean luminance and CFF with that presented by Kelly (1961), it turned out that our *S*s produced CFF several Hz higher than his *S*s under all the three luminance levels, although general pattern of the curves was quite alike. This comparison, however, is not a reasonable one since two studies employed different test patterns even if both used the same sinusoidal waves.

(4) A very clear-cut effect of wave forms on CFF appeared. Different wave forms produced different CFF values, even if they had equivalent amplitude (modulation ratio: 0.29). The highest CFF was obtained with rectangular wave, next to the highest with sinusoidal, followed by the triangular and saw-tooth waves. Thus temporal resolving acuity of the visual system for these wave forms can be ranked in this order.

(5) Exp. 2 showed that there was no appreciable difference in CFF between the two saw-tooth waves.

(6) Ives (1922) maintained that a single function of the ratio of the coefficient of the first periodic term of the Fourier expansion to the mean luminance could explain the differences in CFF values obtained for five different wave forms which were identical

with those used in this study. This empirical formula predicted that by assuming CFF for sinusoidal wave to be 1.00, the one for rectangular wave would be 1.06 times as high as that, the one for triangular wave would be 0.94 times as high, and the one for saw-tooth waves 0.88 times as high, which was in very good agreement with the obtained data. By applying Ives' formula to our data notwithstanding considerable difference in experimental conditions such as mean luminance level of the test field and by multiplying the grand mean CFF value for sinusoidal wave by the above figures to obtain expected CFF values for other wave forms, it was found that under all the luminance levels good coincidence was shown. (See the rightmost column of the Table 1 and also Fig. 2.)

That there was no difference in CFFs between two saw tooth waves, as was shown by the Exp. 2, is in line with Ives' data and is expected by his formula which predicts CFFs for the two saw-tooth waves of 0.85 times as high as that for rectangular wave. Table 2 shows the ratios calculated from CFFs averaged for *S*s to be 0.86, 0.79, and 0.81 for positive ramp saw-tooth and 0.86, 0.81, and 0.81 for negative ramp saw-tooth waves. (In the Table, Ives' expected values are shown in terms of CFF.) These ratios are quite comparable with the expected value of 0.85. Thus, it can be concluded that Ives' theory is tenable not only under scotopic condition investigated by him but under the condition approaching photopic level for CFF stimulus of more than about 10Hz.

References

Brown, J.L. **1965** Flicker and intermittent stimulation. In C.H. Graham (Ed.), *Vision and visual perception*. N.Y. : Wiley, pp. 251–320.

de Lange, H. **1954** Relationship between critical flicker frequency and a set of low-frequency characteristics of the eye. *J. opt. soc. Amer.*, **44**, 380–389.

Goldman, H., König, H., and Mäder, F. **1946** Bemerkungen über das Phanomen des Bewegungsflimmerns und die Definition des Welligkeitsgrades. *Bull. Asso. Suisse des Electricienes*, **37**, 25–30.

Kelly, D.H. **1961** Visual responses to time-dependent stimuli. I. Amplitude sensitivity measurement. *J. opt. soc. Amer.*, **51**, 422–429.

Kennelly, A.E. & Whiting, S.E. **1907** The frequencies of flicker at which variations in illumination vanish. *Nat. Elect. Light Assoc. Conv.*, **30**, 327–340.

Luckiesh, M. **1914** On the growth and decay of color sensations in flicker photometry. *Phys. Rev.*, **4**, 1–11.

Maruyama, K. **1973** Stimulus wave forms formed by the method of "frequency modulation of glow train" and their behavior in the flicker vision at the low frequency region. *JPA Proceedings 37th Annual Convention*, pp. 16–17.

Maruyama, K. & Matsumura, M., **1974** Stimulus waveform and beta motion. *Tohoku Psychol. Folia*, **33**, 134–143.

Ronchi, L. & Bittini, M. **1957** On the influence of the shape of equal energy light pulses on the critical flicker frequency. *Atti della Fond. Giorgio Ronchi*, **12**, 173–179.

(Received August 31, 1976)