MEMOIRS ON THE SCHOOL OF ENGINEERING, OKAYAMA UNIVERSITY Vol. 5, No. 1, SEPTEMBER 1971

On the Trial Production of the Equipment Measuring Many Subjects' Critical Flicker Fusion Frequency at the Same Time

By

Hirokazu ŌSAKI and Susumu KIKUCHI

Department of Industrial Science

(Received May 15 1971)

The equipment measuring the critical flicker fusion frequency (CFF) is made in order to measure many subjects' CFF at the same time. This equipment is defined the multi-flicker. The equipment measuring CFF, used until now is defined the mono-flicker.

It is analysed what factors influence CFF strongly. Then it is made clear that CFF value measured by the multi-flicker can be used to show the brain weariness as well as that of the mono-flicker, and the vigual angle and the intensity of illumination in the room influence CFF value strongly.

§ 1. Introduction

The machine controlled automatically reduces workers' muscular work, but on the contrary, the brain, the monotonous, and the vigilance work, etc. are increased in various fields. These works give rise brain weariness rather than muscular weariness to the worker. Therefore it is important to measure the degree of the brain weariness. The critical flicker fusion frequency (in short, CFF) is used to mesure it. The equipment measuring CFF, used until now has following inconvenient points in using it. Many workers' CFF can not be measured at the same time and there are differences among CFFs measured by various equipments.

In this paper, the authors attempt to make the equipment measuring many workers' CFF at the same time. And it is analysed how the following factors influence CFF.

Factors

1) the position in which the subject watches the equipment measuring CFF.
2) the intensity of illumination in the room.
3) the color and the diameter of the place in which light flickers.

§ 2. Equipment

Figure 1 shows the equipment measuring many subjects' CFF at the same time.

2.1) This equipment is sector type. The disk **A** is roted by the synchronous motor, has two windows, and cuts light from the projector **L.** Then the light flickers in the place **B.** The subject watches the place **B.** The shape of the place **B** is circle. The optical tachometer generator (-TR- 02A, Takeda Riken Industry Co., Ltd.) is connected with the axle of the disk. The optical tachometer generator generates 600 puls/round. The digital frequency counter is used to count the puls generated by the optical tachometer generator.

As the disk has two windows, the frequency (c/s) that the subject recognizes the flicker of light in the place **B** is as follows.

$$F = DF/300 \cdots\cdots\cdots\cdots (1)$$

F : the frequency that the subject can watch in the place **B.**

DF : the frequency which is counted by the digital frequency counter.

When the rotation of the disk is very fast, the subject can not recognize the flicker of light in the place **B.** The rotation of it gradually slows down. Then when the rotation becomes below some rotation, he can recognize the flicker of light in it. In this process, when the subject recognizes the flicker of light in the place **B** first, he presses the reset button of the digital frequency counter. Then the digital frequency counter indicates the frequency when he presses the reset button. The critical flicker fusion frequency (CFF) at that time is equal to the

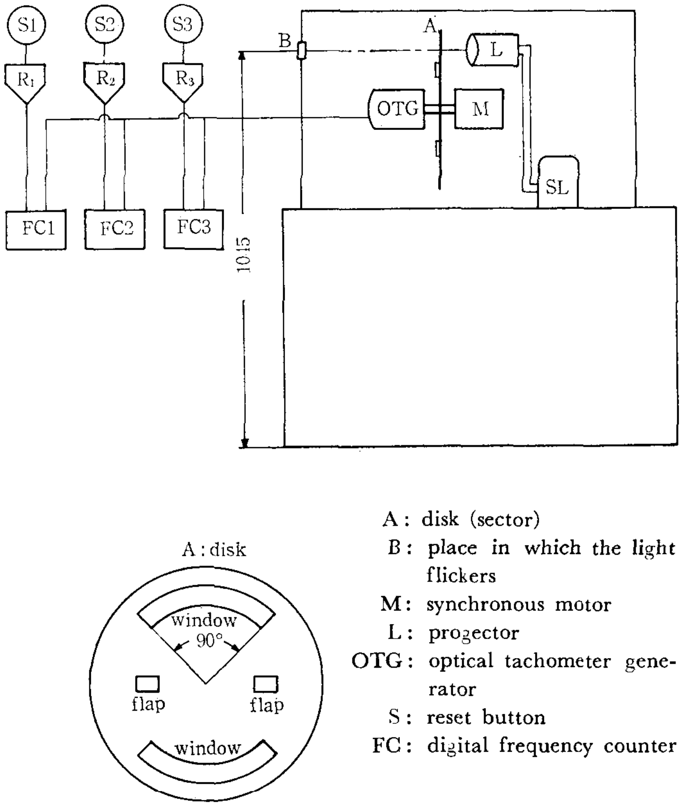

Fig. 1 Equipment measuring many subjects' CFF

frequency which is calculated by the equation (I).

2.2) The flaps are attached to the disk in order to control the rotation of it. The decrement of CFF is 2 c/s from 30c/s to 40 c/s. The height of the place **B** from the floor is nearly equal to that of eyes of the sitting subject.

2.3) The intensity of illumination in the place **B** is 400 lux[1]. The color of the place **B** is red (Kenko filter R-1) or green (Kenko filter PO-1)[1]. It was made clear by K. Hashimoto[1] that the vigual angle of the place **B** should be about 0.5°. Therefore the diameter of the place **B** is determined by the vigual angle and the distance between the subject and the equipment. When the vigual angle is 0.5° and the distance is 3 m, the diameter of the place **B** is 26.2 mm. Table 1 shows the condition of the place **B**.

Table 1. The condition of the place **B**

sign	color	distance	vigual angle	diameter of the place B
R1	red	3m	0.5°	26mm
R2	red	3	1.0	52
G1	green	3	0.5	26
G2	green	4	0.5	35

§ 3. Experimental method

3.1) The equipment measuring CFF, used until now is defined the mono-flicker and that which is made in order to measure many subjects' CFF at the same time is defined the multi-flicker.

The measurement of CFF is done five times at a time. The maximum and the minimum value in five time's measurement are rejected and the mean value of the other three ones becomes CFF value at that time.

The subjects are all male students.

3.2) The following experiment is done in order to examine the difference between CFF value which is measured by the mono-flicker and that measured by the multi-flicker. Figure 2 shows the interval and the order of the measurement of both flickers. In

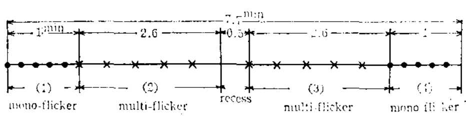

Fig. 2 The interval and the order of the measurement of CFF.
●, × : measurement of CFF

the interval of (1) and (4), CFF is measured by the mono-flicker and in the interval of (2) and (3), it is done by the multi-flicker. There are 0.5 minutes' recess between the interval of (2) and (3). In each interval, CFF is measured five times. All measurement is done in the position of **3.** Figure 3 shows the position in which the subject watches the place **B** of the multi-flicker.

The condition of the place **B** is R1 and the intensity of illumination in the room is 870 lux. The subjects are 17 male students.

3.3) The following experiment is done in order to examine the relation between CFF value and the distance from the multi-flicker to the subject. The intensity of illumination in the

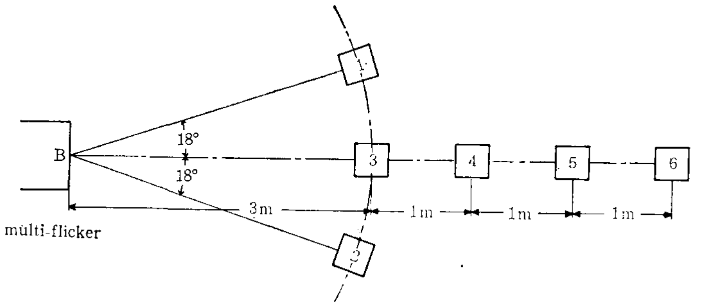

Fig. 3 The position of the measurement of CFF

room is 870 lux. The condition of the place **B** is G1 or G2. In the condition of G1, the measurement of CFF is done first in the position of **3** and next in the position of **4** or **5** or **6.** In the condition of G2, it is done first **4** and next **3** or **5** or **6.** The position of **3** to **6** are shown in Fig. 3. The measurement in the paired positions, for example, **3** and **4,** or **3** and **5,** etc. is done in the interval of (2) and (3) showed in Fig. 2. CFF of the subject is measured in one paired positions in a day.

3.4) The following experiment is done in order to examine the relation between CFF value and the intensity of illumination in the room. The condition of the place **B** is R1. All measurement of CFF is done in the position of **3.**

The measurement of CFF is done first in the condition of 870 lux and next in the condition of 670 lux or 570 or 470 or 370 or 270 or 70 lux. The measurement of the paired intensity of illumination, for example, 870 lux and 670 lux, or 870 lux and 570 lux, etc. is done in the interval of (2) and (3). CFF of the subject is measured in one paired intensity of illumination in a day. The subjects are 16 male students.

There is 0.5 minutes' recess between the interval of (2) and (3). The intensity of illumination in the room becomes from 870 lux to 670 lux or 570 or 470 or 370 or 270 or 70 lux by dimming the light in that recess. The eyes of the subject can be adapted to the darkness in the room in that recess[2].

§ 4. Results

There is a individual difference among each subject's CFF value. Therefore the deviation of CFF value which reduces the individual difference of CFF value is defined as follows.

$F_{ijk}=FF_{ik}-FF_{jk}$

F_{ijk} : the deviation of CFF value of k th subject between FF_{ik} and FF_{jk}.

FF_{ik} : CFF value of k th subject in i th interval

FF_{jk} : CFF value of k th subject in j th interval.

Then the deviation of CFF value of the mono-flicker is equal to F_{41k} or F_{14k} and that of the multi-flicker is F_{32k} or F_{23k}. Hereafter the deviation of CFF value of the mono-flicker is shown by F_{41k} and that of the multi-flicker is done by F_{32k}.

The mean value and unbiased variance of the deviation of CFF value and t-test are calculated by the following formulas.

$$\overline{F}_{ij}=\text{mean value}=\sum_{k=1}^{n} F_{ijk}/n$$

$$U_{ij}^2=\text{unbiased variance}=\sum_{k=1}^{n}(F_{ijk}-\overline{F}_{ij})^2/(n-1)$$

$$t_0=\text{result of } t\text{-test}=\overline{F}_{ij}/\sqrt{U_{ij}^2/n}$$

n = number of data

4.1) The difference between CFF value measured by the mono-flicker and that of the multi-fliker.

Table 2 shows the mean value and the unbiased variance of the deviation of CFF value

Table 2. The comparison of the measurement of mono-flicker and that of multi-flicker.

equipment	deviation of CFF value		the results of t-test
	mean	unbiased variance	
mono-flicker	−0.7712c/s	1.4217	2.6667*
multi-flicker	−0.6841	0.7464	3.2654*

$n=17$ *: rejects at the level 5%

and the result of t-test in each flicker. It is made clear that the mean values of both flickers are nearly equal and are negative. Further it is made clear from the results of t-test that CFF value measured by the mono-flicker in the interval of (4) is significantly smaller than in (1) and the same result is obtained from CFF value measured by the multi-flicker. Therefore CFF value decreases during the measurement. This fact is pointed out by P. Rey[3], too.

The unbiased variance of the deviation of CFF value of the multi-flicker is smaller than that of the mono-flicker, but the former is not significantly smaller than the latter. The unbiased variance indicates individual difference of the deviation of CFF value. The smaller the unbiased variance becomes, the smaller the individual difference becomes. Then the remarkable phenomenon can be recognized more accurately from the deviation of CFF value of the multi-flicker.

As the unbiased variances of both flickers are statistically equal, the difference between the mean value of the deviation of CFF value of the multi-flicker and that of the mono-flicker is examined by another *t*-test. Then it is made clear that the mean values of the deviation of CFF values of both flickers are statistically equal.

From these results CFF value measured by the multi-flicker can be used to show the brain weariness during work as well as that of the mono-flicker. And it is analysed what factors influence strongly CFF value measured by the multi-flicker.

4.2) The decrement of CFF value measured by the multi-flicker during the measurement

The decrement of CFF value is examined in the various conditions. Table 3 shows the mean value and the unbiased variance and the result of *t*-test in various conditions of the place **B** and positions. The subjects are all male students.

Table 3. The decrement of CFF value during the measurement in various conditions.

sign	condition of the place B	position of the subject	deviation of CFF value		results of *t*-test	number of the subject
			mean	unbiased variance		
R13	R1	3	−0.654 c/s	0.2986	5.356*	20
R23	R2	3	−0.510	0.3102	4.096*	20
G13	G1	3	−0.301	0.2611	2.629*	20
G15	G1	5	−0.532	0.2146	4.876*	18
G24	G2	4	−0.436	0.3634	2.980*	17

* : rejects at the level 5 %

The results of *t*-test are all rejected at the level of 5%. Therefore it is made clear that CFF value decreases significantly during the measurement in each condition. Further it is made clear that the unbiased variances of the deviation of CFF value are statistically equal in various conditions. Therefore the another *t*-test can be used to examine the difference of the mean values in two different conditions. Then it is made clear that there is the significant difference between the mean value of the condition of R13 and that of G13. The decrement of the CFF value is the smallest in the condition that the color of the place **B** is green, the diameter of it is 26 mm and the distance from the subject to the multi-flicker is 3 m. Therefore if the distance is nearly 3 m, green should be selected the color of the place **B.** Then the decrement of CFF value is the smallest during the measurement.

4.3) The relation between CFF value and the distance

It is made clear that the decrement of CFF value in the same position, in the condition of G1 or G2 of the place **B** is smaller than that in the condition of R1 or R2. Therefore the condition of G1 or G2 in the place **B** is used to examine the relation between CFF value and the distance. The distance from the multi-flicker to the position of **3** or **4** or **5** or **6** is 3 m or 4 m or 5 m or 6 m. The diameter or the place **B** is settled as follows in the condition of G1 or G2. The vigual angle of the place **B** is determined to be 0.5° in the position of **3** or **4.** Therefore in the condition G1, CFF value of the position of **3** is the criterion value to CFF value of the other positions. Then the deviation of CFF value is shown by F_{i3k}, $i=3, 4, 5, 6$. And in the condition of G2, CFF value of the position of **4** is the criterion value to CFF value of the other positions. Then it is shown by F_{i4k}, $i=3, 4, 5, 6$.

Table 4 shows the mean value and the unbiased variance of the deviation of CFF value in various positions. In this table, the mean values and the unbiased variances in 3—3 of G1 and 4—4 of G2 are those of the conditions of G13 and G24 in Table 3.

Table 4. The relation between the distance and CFF value.

condition of the place B	between two positions	deviation of CFF value: mean	deviation of CFF value: unbiased varance	number of subject
G1	3−3	−0.301	0.261	20
	3−4	−2.38	1.065	18
	3−5	−3.88	1.720	18
	3−6	−4.87	3.221	17
G2	4−3	0.792	0.263	17
	4−4	−0.436	0.363	17
	4−5	−2.164	1.479	16
	4−6	−3.249	2.828	16

It is made clear that the longer the distance from the subject to the multi-flicker becomes, the lower CFF value becomes. And the unbiased variance of the deviation of CFF value increases accordance with the increase of the distance. Figure 4 shows the relation between the mean value and the unbiased variance of the deviation of CFF value and the distance. Then it is made clear that the rate of the decrement of the mean value and that of the increase of the unbiased variance are nearly in proportion to the logarithm of the distance in each condition.

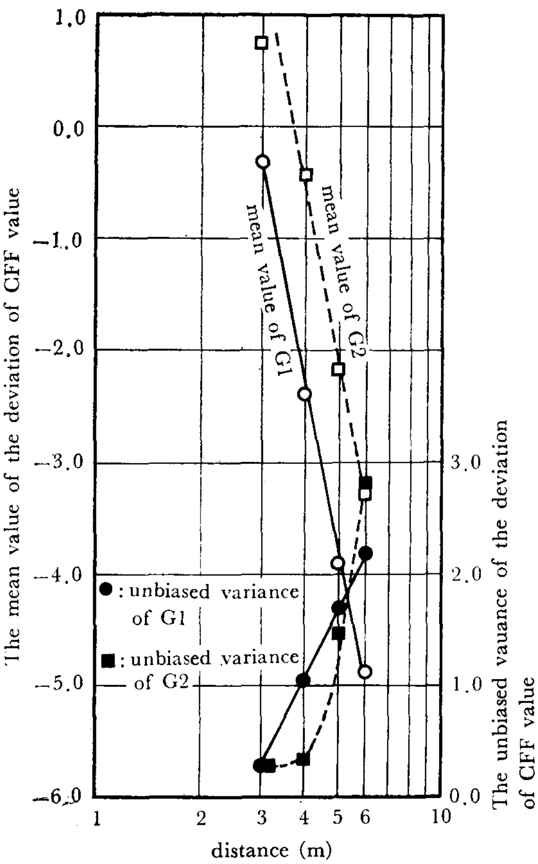

Fig. 4 The relation between the CFF value and the distance

The diameter of the place **B** is determined by the vigual angle and the distance. Then the relation between CFF value and the vigual angle is examined. Figure 5 shows the relation

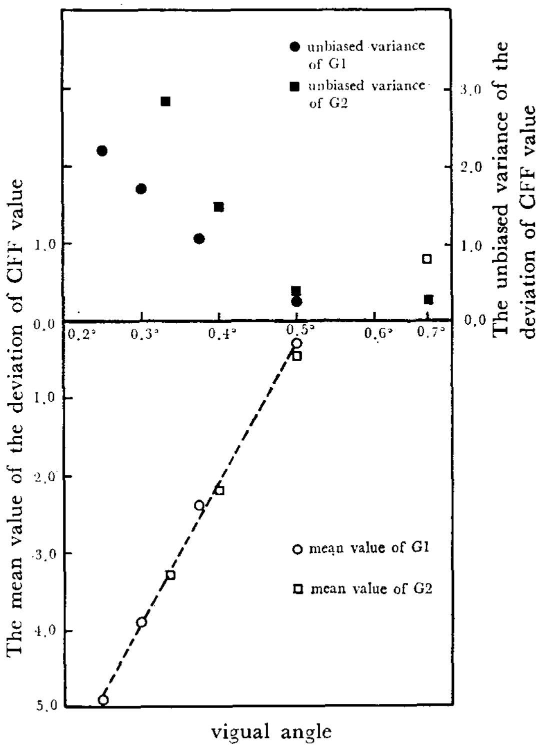

Fig. 5 The relation between CFF value and the vigual angle.

between the mean value and the unbiased variance of the deviation of CFF value and the vigual angle. It is made clear that the mean value of the deviation of CFF value is nearly in proportion to the vigual angle from 0.2° to 0.5° in both conditions. But the unbiased variance is independent of the vigual angle. And the unbiased variances from 0.5° to 0.7° are significantly smaller than the others. Therefore it is desirable for CFF value to be measured in the neighbourhood of the position in which the diameter of the place **B** is determined by the distance and the vigual angle.

Further the relation between CFF value and the positions which the distance is equal in but are apart right or left from the position of **3** is examined. These positions are shown in Fig. 3 by the notation of **1** and **2.** The condition of the place **B** is R1 or R2. The measurement of CFF is done first in the position of **3** and next in the position of **1** or **2.** Then the deviaiton of CFF value is shown by F_{i3k}, $i=1, 2$.

Table 5 shows the mean value and the unbiased variance of the deviation of CFF value and the result of t-test in each condition.

Table 5. The relation between CFF value and the positions which are apart right or left from the position of **3.**

condition of the place B	the position of the subject	deviation of CFF		result of t-test	number of subject
		mean value	unbiased variance		
R1	1	−0.434	0.2574	3.311*	15
R1	2	−0.696	0.2645	5.743*	18
R2	1	−0.404	0.2954	3.245*	19
R2	2	−0.381	0.2751	3.165*	19

It is made clear that the mean values in the positions of **1** and **2** are significantly lower than those in the position of **3.** But CFF value decreases during the measurement. And the rate of the decrement in the position of **3** is -0.654 in the condition of R1 and -0.510 in R2. Further it is made clear that the unbiased variance is statistically equal each other. Therefore it is made clear that the decrement of CFF values of the positionsof **1** and **2** is statistically equal to the decrement of the position of **3.** Then CFF values measured in the positions in which the distance is equal are equal.

4.4) The relation between CFF value and the intensity of illumination in the room

CFF value measured in the condition of 870 lux is the criterion value to the others. Table 6 shows the mean value and the unbiased variance of the deviation of CFF value in various intensity of illumination in the room.

Table 6. The relation between the intensity of illumination in the room and CFF value.

intensity of the illumination (lux)	the deviation of CFF value	
	mean	unbiased variance
870	−0.654 c/s	0.2986
670	−0.540	0.3026
570	−0.916	0.6912
470	−1.520	0.5895
370	−1.646	1.0132
270	−2.085	1.1045
70	−2.564	1.0771

$n=16$

It is made clear that the mean values and the unbiased variances are nearly equal each other in the condition of 870 lux and 670 lux. Figure 6 shows the relation between the mean

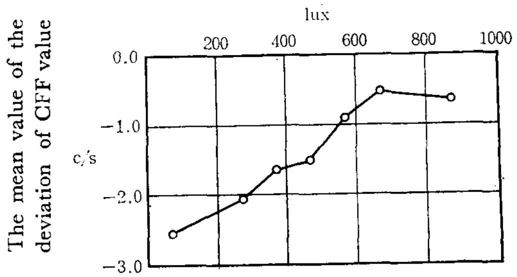

Fig. 6 The relation between CFF value and the intensity of illumination in the room.

value of the deviation of CFF value and the intensity of illumination in the room. It is made clear that when the intensity of illumination is less than 670 lux, CFF value is nearly in proportion to the intensity of illumination in the room, but the unbiased variances are significantly greater than those of 870 lux and 670 lux. Then it is made clear that when the intensity of illumination in the room is higher than 670 lux, the intensity of illumination in the room does not influence CFF value.

§ 5. Conclusion

The equipment which measures many subjects' critical flicker fusion frequency (CFF) at the same time is manufactured for trial. This equipment is defined the multi-flicker. And the equipment measuring CFF, used until now is defined the mono-flicker. It is analysed what factors influence CFF strongly. Then the following results are obtained.

1) The mean value of the deviation of CFF value of the multi-flicker is nearly equal to that of the mono-flicker statistically. Further the unbiased variance of the deviation of CFF value is less than that of the mono-flicker. The CFF value measured by the multi-flicker can be used to show the brain weariness as well as that of the mono-flicker. Further it is made clear that CFF value decreases during the measurement.

2) CFF value is nearly in proportion to the vigual angle of the place in which light flickers. But the unbiased variane of the deviation of CFF value doesn't depend on the vigual angle. Further the positions in which the distance from the multi-flicker to the subject is equal, CFF values measured in those positions are equal each other.

3) CFF value is nearly in proportion to the intensity of illumination in the room under 670 lux. And when the intensity of illumination in the room is higher than 670 lux, CFF value changes a little.

From these results, it is made clear that the multi-flicker can be used as well as the mono-flicker.

Reference

1) K. Hashimoto : Jap. J. Ind. Health, **5** (1963), 568, 569.
2) Society of Japanese Human Engineering : *Human Engineering Handbook*, (1966), 69, Kinbara Press. Co., Ltd..
3) P. Rey, and J. P. Rey : Ergonomics, **8** (1965), 173.