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The Apparatus to Measure the Multi-point Critical Flicker Fusion Frequency (MCFF)

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SYNOPSIS

In this paper, we mentioned the apparatus developed to measure CFFs at the various point of the retina. Eleven CFFs measured at the central retina of both eyes(used usually) simultaneously, at the central retina of each eye separately, and at four points of the peripheral retina of each eye were analyzed together and referred to as the multi-point critical flicker fusion frequency(MCFF). MCFF can be used to estimate the level of cortex activity, since the temporal and nasal parts of each eye are connected to different visual cortexes through the optic nerve. As the apparatus used to measure the MCFF was controlled by a micro-computer, the order of measurements and the calculation were done automatically.

1. INTRODUCTION

It is said that the critical flicker fusion frequency(CFF) shows the level of the activity of the brain. CFF measured with both eyes is used widely to evaluate the mental or physical load during work, and many authors(Simonson E., et al.,(1950)[1], Hashimoto K.,(1960)[2], Oshima M.,(1964)[3], and Osaki H., et al.,(1976)[4]) have estimated the critical level of various kinds of work with CFF.

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Osaki H., et al.,(1977)[5] developed a method to measure the luminance(cd/m^2) of the optical system of the CFF apparatus with a luminance meter, and Ogata M., et al.,(1977)[6] developed an apparatus using a green LED as the target to measure the CFF.

Eccles J.C.,(1974)[7] and Tsunoda T.,(1978)[8] have made it known that the left(dominant) hemisphere of the cerebrum performs analytical verbal, arithmetical and computer like function, while the right(minor) hemisphere performs musical, pattern-sense, synthetic, geometrical, and spatial function(Fig. 1).

Lassel N.A., et al.,(1978)[9] discovered by measuring the flow of blood in the brain that different regions of the cerebrum are activated according to kind of work.

Therefore, by measuring the activity of both hemisphere with CFFs, the work load can be evaluated precisely.

In this research, we developed an apparatus to measure the CFFs of various parts of the retina, and a method to estimate the level of activity of cortex.

2. PRINCIPLE

The verbal, analytical, sequential, arithmetical and computer-like, and ideational abilities are centered in the left(dominant) hemisphere. And the musical, pictorial and pattern-sense, geometrical and spatial,

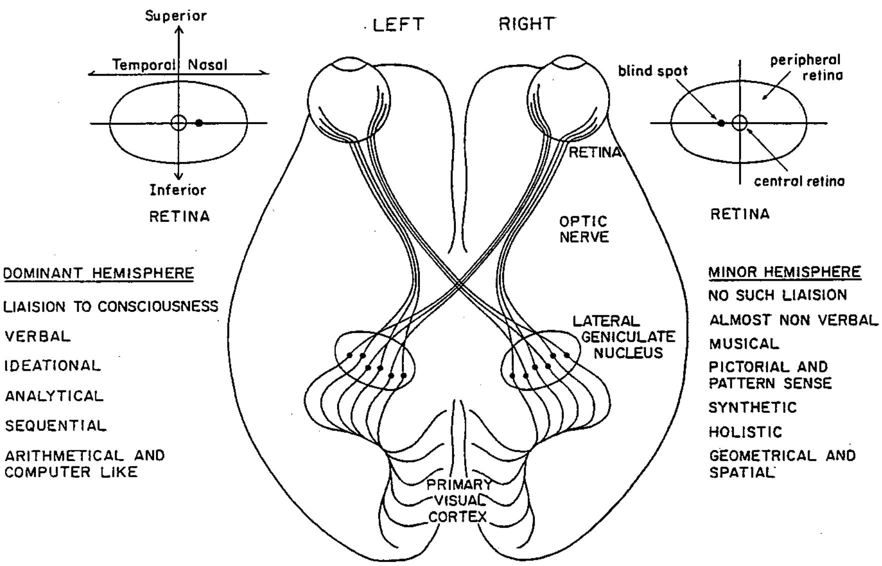

Fig. 1, Visual pathway and performance of each hemisphere.

synthetic, and holistic abilities are centered in the right(minor) hemisphere of the cerebrum(Fig. 1).

The activity of the dominant hemisphere influences that of the minor one through the callous body, but the converse is not true.

Therefore the activity of both hemispheres should vary as the type of work changes. The nervous tissue of the retina can be divided into four parts by vertical line, that is, temporal and nasal part, and by horizontal line, that is, superior and inferior part. These tissues are connected to different visual cortexes through the optic nerve (Fig. 1). The density of cones and rods are equal at about 6 degrees of the visual angle, and there is a blind spot at about 15 degrees.

Fukuda T.,(1978)[10] showed that the CFF was the highest at the central retina. It decreased rapidly up to 10 degrees of visual angle and done gradually above 10 degrees at the peripheral retina.

If the CFF could be measured at each quadrant of the retina of each eye, the level of the activity of each cerebral hemisphere could be estimated. We developed an apparatus to measure CFFs at each quadrant of the retina of each eye. CFFs at the central retina of each eye and of both eyes(the usual CFF) can be measured at the same time with this apparatus.

Eleven CFFs considered collectively in this paper are referred to as the multi-point critical flicker fusion frequency(MCFF). CFFs of the temporal part of the left eye and the nasal part of the right eye can estimate the level of activity of the dominant hemisphere. Those of the temporal part of the right eye and nasal part of the left eye can estimate the level of activity of the minor hemisphere.

3. EQUIPMENT

The equipment was constructed of three parts: the eye hood, the power source, and the micro-computer(Fig. 2).

In the eye hood, the distance from the eye to the targets was 30 cm. The ocular part was slid right or left to measure the MCFF of each eye. In the visual field of the eye not being measured, a light background(25 cd/m^2, 25mmϕ) was set up to avoid the effect of light adaptation(Fig. 3).

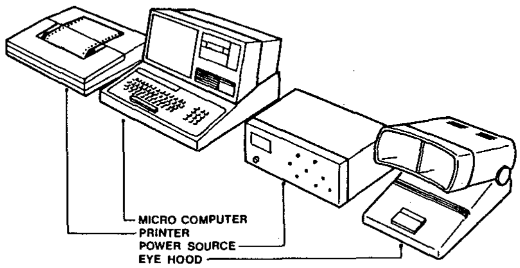

Fig. 2, Apparatus to measure MCFF.

The targets of the flicker points(P_1, P_2, P_3, and P_4) were green LEDs(120 cd/m^2, 2.0 mmϕ) [6], and set up the center of the light background(25 cd/m^2, 25 mmϕ) [5]. The relationship between the targets and CFFs of each quadrant of the retina are shown in Fig. 4.

A red LED(100 cd/m^2, 2.0 mmϕ) on a light background(25 cd/m^2, 25 mmϕ) was set up in the center(point C) of the visual field, and was used to fix the eye movement at the central retina on measuring the CFFs on the quadrant of the retina.

The targets(P_1 to P_4) were laid in a circle 60 mm in diameter around point C, and on the lines passing through point C perpendicularly intersecting each other. The inclination of one line was 45 degrees from the horizontal.

The visual angle of the targets from point C was 5.5 degrees. At the measurement, only one target and its light background was lit.

The power source was driven 7 light tubes for the light background, 4 green LEDs for the targets, and one red LED. 4 green LEDs were gone on and off at the interval 1 : 1 between 10 and 59 Hz. Only one green LED and its background was lit at a time.

The micro-computer was used to control the order of lighting up the targets(P_1 to P_4 and C), and their respective backgrounds, and to assign the downward or upward of the frequency of flicker and

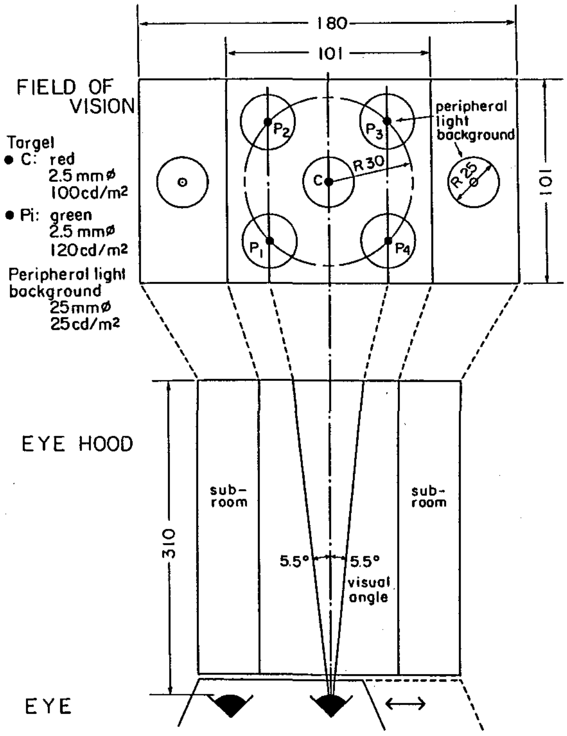

Fig.3, Layout in eye hood.

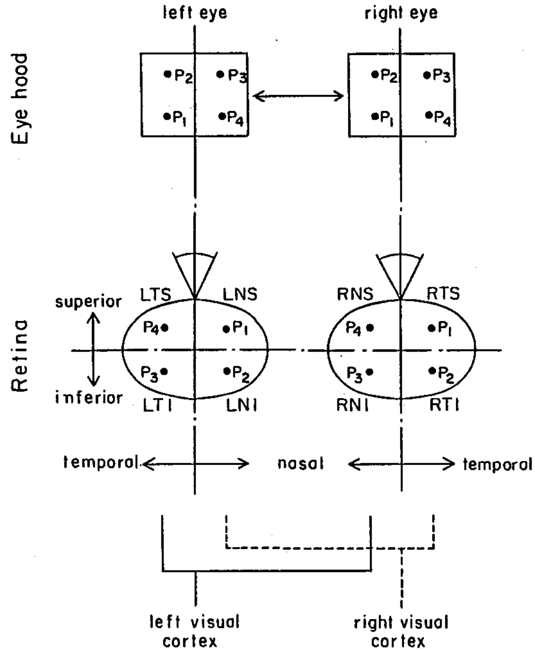

Fig. 4, Correspondence between target and retina.

the speed(1 Hz or 2 Hz). Parameters were changed in our program(BASIC language), as necessary. The message was displayed on a CRT to the subject and operator. The results of the MCFF were calculated and displayed on the CRT as in Fig. 5 and if necessary, printed out by the printer or stored to the floppy disc or micro-casette tape.

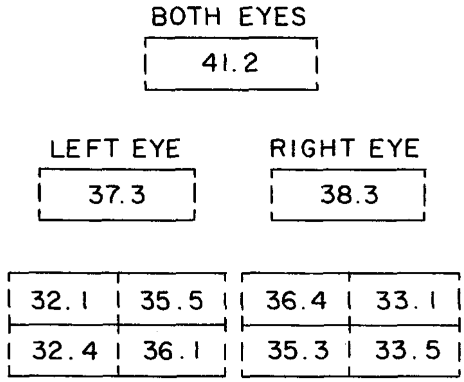

Fig. 5, Output format of MCFF.

At the measurement, as the subject recognized the flicker of a target, he pressed a push-button fitted up the eye hood. The frequency(Hz) of the flicker at that time was sent to the micro-computer from the power source.

4. MEASUREMENT METHOD

At each position, the frequency(Hz) was measured five times. And the CFF was shown as the mean value of three measurements except for minimum and maximum value in five measurements.

For the CFF of both eyes, the subject looks at the target P_1 with the ocular part set so the target P_1 can be seen with both eyes.

For the CFF of each eye, the ocular part was slid to the right side for the left eye and to the left for the right eye. The CFF was measured by either lighting the target P_1(P_4, as the right eye) and its light background with the subject looking at P_1 with the central retina of one eye, or lighting up the red LED(C) and its background and one of targets(P_i) and its light background. The order of the lighting was P_1, P_2, P_3, and P_4. This order can exchange by the program of a micro-computer. The CFF of each quadrant of the retina was thus measured by looking at C in the central retina and P_i in the quadrant of the retina.

5. ANALYTICAL METHOD

The eleven CFFs denoted as follows.

BCF : both eyes.

LCF : the central retina of the left eye.

RCF : the central retina of the right eye.

LTSCF : the temporal and superior quadrant of the peripheral retina of the left eye.

LTICF : the temporal and inferior quardant of the peripheral retina of the left eye.

LNSCF : the nasal and superior quadrant of the peripheral retina of the left eye.

LNICF : the nasal and inferior quadrant of the peripheral retina of the left eye.

RTSCF
RTICF
RNSCF
RNICF : the CFFs of the right eye corresponding to LTSCF, LTICF, LNSCF, and LNICF.

LTSCF, LTICF, RNSCF, and RNICF measured the level of the activity of the dominant hemisphere, and the others the minor hemisphere. Using these CFFs, we can estimate the level of the activity of each hemisphere.

The eleven CFFs were shown in a MCFF chart in which one showed the CFFs according to the position of the retina and the other part according to the cerebral hemisphere.

To evaluate the work load, MCFFs were measured at the beginning and finish of a work. The rate of variation(RV) of each CFF, a measure of the work load, was calculated as follows:

$$RV = \frac{\text{CFF at finish} - \text{CFF at beginning}}{\text{CFF at beginning}} \times 100$$

6. EXAMPLE OF MEASUREMENT

To make clear the relation among the MCFF, subject' MCFFs were measured at 9:00, 12:00, 15:00, and 18:00 in the course of two weeks (May 7 - 20, 1982). Here the result of one subject(male student, 23 years old) was shown in detail.

The number of data was 48 in each CFF, the variance among the 11 CFFs was tested by Bertlett's test of homogenity of variance[11]. Further comparison among means of CFFs was tested by Scheffe's test using the result of one-way ANOVA[11].

6.1 Mean and Variance of MCFF

The MCFF chart is shown in Fig. 6. BCF was the highest at 47.08±

1.009 Hz. RCF(45.14±1.598 Hz) was slightly lower than BCF, and LCF(41.2±1.659 Hz) was yet lower.

The mean value of the CFF at the peripheral retina were distributed in the interval of 41.08 to 43.60 Hz, and were lower than BCF and RCF. This result agrees with that of Fukuda T.,(1978)[10]. the variances of all CFFs were not equal to each others at the significant level of 5 %. The unbiased variance of BCF was the smallest at 1.019. Therefore as BCF was high and its variation small, it can be said that BCF was fairly stable as the work load varied. As the variances of the 10 other CFFs besides BCF were equal to each other, a comparison among the means was tested by one-way ANOVA. There were significant differences among 8 CFFs of the peripheral retina. In the left eye, LTSCF was 43.60 Hz and was significantly higher than LTICF and LNICF by Scheffe's test. The difference between LNSCF and LNICF also was significant. In right eye, the 4 CFFs were equal to each other.

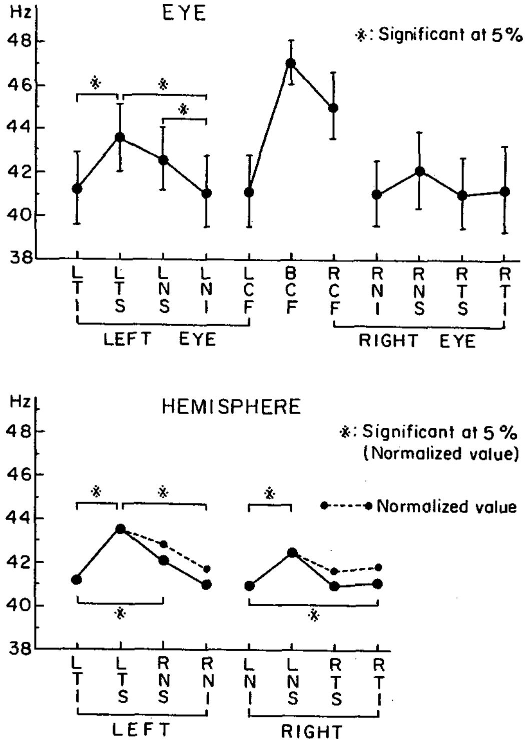

Fig. 6, MCFF chart of one subject.

The mean value(42.03 Hz) of the left peripheral retina was significantly higher than that(41.53 Hz) of right one at the significant level of 5 % by Scheffe's test. Therefore there was a difference between the eyes.

Further, we examine the variation of CFFs in each hemisphere using the original CFFs and the normalized CFFs which were multipled by the ratio(1.01) of the mean value of the right eye to that of the left eye. In the left hemisphere, LTSCF was significantly higher than the others, and there was no significant difference among the 3 other CFFs besides LTSCF by original CFFs. But using the normalized CFFs, the difference between LTSCF and RNSCF became insignificant, while that between LTICF and RNSCF became significant. In the right hemisphere, LNSCF(42.63 Hz) was significantly higher than the others, and the 3 other CFFs were equal to each other by original CFFs. Using the normalized CFFs, only the differences between LNICF and LNSCF, and between LNICF and RTICF were significant. We can use MCFF to estimate the level of activity in the hemisphere.

6.2 Correlation Coefficient among MCFF

The corrrelation coefficients are shown in Fig. 7. The correlation coefficients were distributed between 0.05 and 0.65. Since the coefficients between BCF and the other CFFs ranged from 0.05 to 0.36, it can be assumed that the 10 other CFFs measured the level of activity of the parts of cortex not measured by CFF used usually.

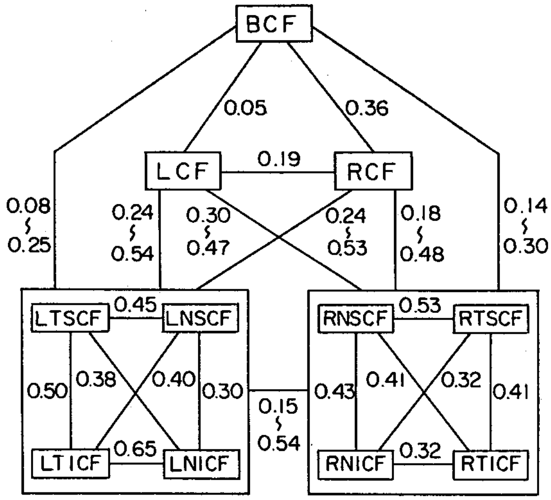

Fig. 7, Correlation coefficient among MCFF.

Some of the other subjects showed the high correlation partially.

6.3 Variation daily or weekly

The mean values of MCFF were calculated at 9:00, 12:00, 15:00, and 18:00 to show the variation in a day. As the values were different from each other from the above analysis, each CFF was normalized as follows:

CF_{ij} is the mean value of CFF at time i (i=1,2,3,4), and at position j (j=1,2,...,11).

Z_{ij} is the normalized score at time i and at position j as follows.

$$Z_{ij} = \frac{CF_{ij} - \min_{1\le i\le 4} CF_{ij}}{\max_{1\le i\le 4} CF_{ij} - \min_{1\le i\le 4} CF_{ij}} \times 90 + 10$$

Then for each j, $\min_{1\le i\le 4} Z_{ij} = 10$ and $\max_{1\le i\le 4} Z_{ij} = 100$.

The radar chart (Fig. 8) for each time was drawn using the normalized score. The left side of the chart shows LCF and the 4 CFFs of the left hemisphere, and the right side RCF and the 4 CFFs of the right hemisphere. The center of upper side shows BCF.

At 9:00, almost all CFFs except for RNSCF were low, that is, it can be said that the level of the activity of most parts of the brain was low. At 12:00, as BCF, and RTSCF, RTICF, and LNSCF representing the right hemisphere became high, the right hemisphere became active. At 15:00, LTSCF and LTICF representing the left hemisphere became high, but CFFs except for LNICF of the right hemisphere was low. At 18:00, BCF was low, but CFFs except for RNSCF were all high. Thus both hemisphere of this subject were activated at 18:00. In this manner, the level of brain activity could be estimated.

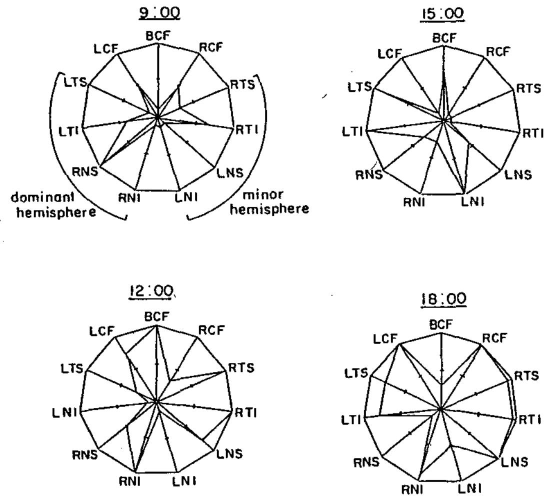

Fig. 8, Variation of MCFF in a day.

The radar chart of a week is shown in Fig. 9. CF'_{ij} is the mean value of CFF in i-th day of the week(i=1,2,...,6) and at position j (j=1,2,...,11). Z'_{ij} is the normalized score in i-th day of the week and at position j. Then for each j, $\min_{1\le i\le 6} Z'_{ij} = 10$ and $\max_{1\le i\le 6} Z'_{ij} = 100$.

BCF did not coincide with those of CFFs of the peripheral retina. From Monday to Friday, the brain was partially activated, and BCF was fairly high except for Tuesday. On Saturday the brain was quite active, and BCF became high. Therefore MCFF gave a more precise evaluation of the work load than the usual BCF.

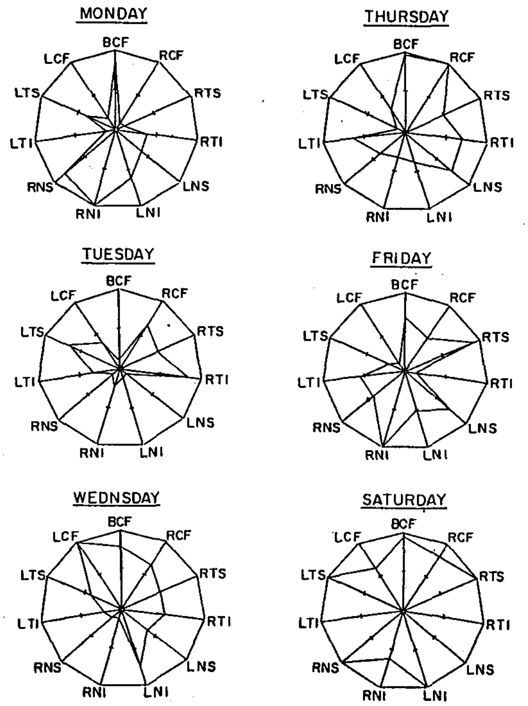

Fig. 9, Variation of MCFF in a week.

7. CONCLUSION

We developed the apparatus to measure the CFFs of various parts of the retina to evaluate the work load and to estimate the level of activity of the cerebral cortexes more precisely. Eleven CFFs, that is, BCF at the central retina of both eyes(used usually), LCF and RCF at the central retina of each eye separately, and 8 CFFs(LTSCF, LTICF, LNSCF, LNICF, RTSCF, RTICF, RNSCF, and RNICF) at four quadrant of the peripheral retina of each eye were measured by this apparatus. These CFFs referred to as the multi-point critical flicker fusion frequency (MCFF).

It was made clear from the results that the MCFF can be used to estimate not only the work load but also the level of activity of both hemispheres more precisely than the usual CFF.

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