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Some Observations on EEG Response to Photic Flicker Stimulation *

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By applying a combined method of crosscorrelation and frequency analysis to EEG tracings, the average response patterns to photic flicker stimulation with a frequency in the alpha wave range were sorted out, even when the application of the frequency analysis only could not separate the response from the irrelevant oscillations to the stimulation.

During the stimulation, low volage fast pattern (alpha blocking state), in which the response was hard to recognize by visual inspection of the tracing, occurred in the EEG tracings from time to time. In the frequency spectra of them, however, not only a peak at the stimulating frequency, but the other ones at slightly higher frequency and sometimes with subharmonic frequency were appeared to suggest they are the response to the stimulation, though they are far lower than the peak of the dominant alpha wave before the initiation of the stimulation, rised up at the stimulating frequency in the power spectra of the crosscorrelogram between the stimulation and the tracing to indicate the other peaks were not related response, at least directly, to the stimulation, but by others.

It is well recognized that the electroencephalogram (EEG) is driven by a photic flicker stimulation with a frequency of alpha wave is estimated in many cases (ADRIAN AND MATTHEWS[1] 1934, DURUP AND FESSARD[7] 1935, TOMAN[37] 1941, MOTOKAWA AND MITA[18] 1941, MUNDY-CASTLE[20,21] 1953, HUGHES, CURTIN AND BROWN[11] 1960) by visual inspection of the EEG tracing during the stimulation. In such tracings, however, the waves unrelated to the stimulation are usually superimposed on the driven waves distorting and/or masking them. Later the equipment for automatic EEG frequency analysis and the correlater for autocorrelation analysis (WALTER, DOVY AND SHIPTON[38] 1949, IMAHORI AND SUHARA[12] 1949, WALTER AND WALTER[39,40] 1949, WALTER [41,42] 1950, 1960, BRAZIER AND CASBY[3] 1952, SUHARA[36] 1952, DAWSON[6] 1954, BRAZIER AND BARLOW[4] 1956, YUZURIHA[43] 1960, STORM VAN LEEUWEN AND BEKKERING[35] 1952, BARLOW[2] 1960) were applied to analyze the average frequency-pattern and time-pattern of EEGs respectively. Even in analyzed data,

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the influence of the above mentioned indifferent waves is also included. Though visual inspection of EEG tracing is necessary (COHN[5] 1952) for the first step, it is also important to carry out suitable analytical treatments to find response patterns masked by the irregular EEG patterns.

By applying the crosscorrelation method, SATO (1956)[22] (1957)[23-26] (1958)[27] (1959)[28,29] SATO AND MIMURA (1956)[30], SATO, MIMURA et al. (1957)[31], SATO, OZAKI et al. (1957)[32], (1959)[33], MIMURA (1958)[17], HONDA (1959)[10], and MASUYA (1960)[16], eliminated the wave unrelated to the stimulation in the EEG tracing during the flicker or single flash stimulation, and succeeded not only in determining the average response time-pattern of the driven wave but also in measuring quantitatively the fine structure of the power spectrum. In addition, they established a new physiological significance of the EEG from the standpoint of the random process in a servo system. That is to say, the "transforming action" of the brain wave generator corresponds to the frequency response function in the frequency domain and the transfer function in the time domain of a servo system. Recently SATO, OZAKI et al.[34] found that the "transforming action" is nothing but the "average activity", which is defined as a highly extended concept of the "excitability" in modern physiology.

Here, the authors report on some new results obtained by applying the same methods to EEG tracing during the photic flicker stimulation.

METHOD

EEG tracings were photographed on bromide paper by a 3-elements electromagnetic oscillograph (Yokogawa Electric Work) through 4-stage balanced amplifiers. The time constant of the recording systems was

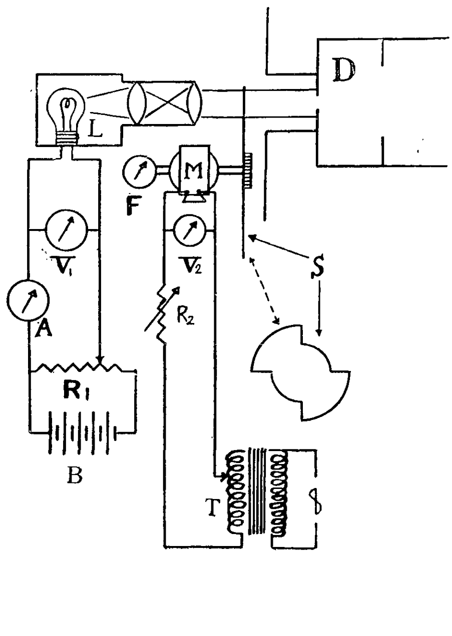

FIG. 1. Experimental apparatus for the flicker stimulation.

Light beam from the 300 watts tungsten lamp L, to which D.C. current was supplied from the battery B of 100 V, 200 AH. It was interrupted by a rotation sector S, which was driven by the motor M. The current supply to the motor was controled by the transformer T and the variable rheostat R_2. The flickering frequency was measured and controled by the trochometer F. The light beam was projected onto a white curtain hung on the wall in the dark room D to stimulate the subject's eyes looking at the curtain in a relaxed state. Observing the ammeter A and the voltmeter V_1, the intensity of the light beam was controled by sliding the variable rheostat R_1.

0.1 sec. Flickering light with a dark-light ratio 1 : 1 was delivered with the equipment shown in Figure 1 to normal male adult subjects in a dark room.

In some cases, the flickering stimulation was delivered through a green or a red glass filter. The intensity of the stimulation was determined biologically by measuring the critical flicker fusion frequency of the subject, since this frequency is closely related to the intensity of the flicker stimulation[8] and visual acuity[9]. The intensity of the stimulation used was the critical flicker fusion frequency of approximately 11–13 flashes per second, which lies in the range of linear relationship to the logarithmic intensity of illumination (Fig. 2) and was supposed to be corresponded to approximately 0.2–0.4 lux. The subject in the dark room in a relaxed condition was asked to look at a white curtain hanging on the wall upon which the flickering light was projected diffusely. The stimulation was traced simultaneously on the EEG tracings through a photo cell. Crosscorrelograms between the EEG tracings and the stimulation were computed to analyze the driven wave by the principle shown in a previous paper (SATO[24] 1957, Appendix II). Power spectra of the control EEG tracings before and during the stimulation and the crosscorrelogram were computed by applying 120 (15×8) or 72 (9×8) ordinated double harmonic analysis (Kobayashi[14,15] (1953) (1955)). The resolving power of the 120 and 72 ordinates frequency analysis was about 0.4–0.5 and 0.6–1.0 c/sec respectively.

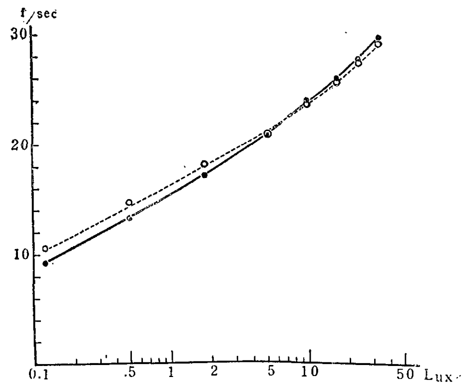

FIG. 2. Critical flicker fusion frequency and the intensity of illumination.
Abscissa: The logarithmic intensity of illumination of flickering photic stimulation.
Ordinate: The critical flicker fusion frequency in flashes per sec (f/sec).
Black circles: right eyes.
White circles: left eyes.

RESULTS AND DISCUSSION

1) Visual Inspection of the EEG Tracings.

To estimate the EEG response caused by a rhythmic stimulation, visual inspection of the EEG tracing is very important as the first step. In the case illustrated in the middle tracing (IIBI) in Figure 3, alpha waves seem to be synchronised with the rectangular stimulation curve below. While no shift of phase occurs between the EEG tracing and the stimulation curve at first, the shift increases gradually to reach the phase reversal. This finding indicates that there is a slight difference in the frequency between the EEG tracing and the stimulation curve as demonstrated in the frequency spectrum on the right side. During the alpha-blocking state, on the contrary, as illustrated in the lowest tracing in Figure 3 and the latter half of the tracing during the stimulation in Figure 4 (II (2),), there are more difficult problems for visual estimation since the fast waves distort and/or mask the driven waves. Such instances occurred from time to time during the stimulation. In the case of rhythmic stimulation, especially with a frequency in the alpha band, it is therefore often difficult to estimate exactly by visual inspection the effect of the stimulation.

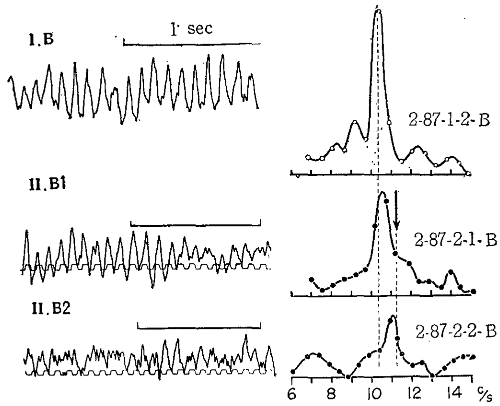

FIG. 3. A transient frequency shift of the alpha wave during photic flicker stimulation.

IB: Control EEG tracing led from occiput and its frequency spectrum before the onset of the flicker stimulation. IIB1 and IIB2: Those of during the stimulation. The tracing of IIB1 is continued to IIB2. Rectangular curve below the EEG tracing is the stimulation curve, in which the lower horizontal parts indicate the "on" period and the upper ones of "off" one. Vertical arrow in the frequency spectrum points the location of the stimulating frequency. The relative intensity of the stimulation corresponded to the flicker fusion frequency of 12.5 flashes per sec (f/sec). (See text)

2) *Evaluation by Frequency Analysis.*

As is well known, frequency analysis is useful in evaluating EEG tracings because the power spectrum shows their average frequency-pattern of which the physiological significance was recently studied by SATO, OZAKI et al.[34]

By comparing power spectra of EEG tracings before and during stimulation, it is observed that EEG response is indicated by the peak newly appeared at the stimulating frequency in the latter to show synchronized response activity.

In the case illustrated in Figure 3, such a peak would be conspicuous in the frequency spectra. Even in the alpha-blocking state (IIB2), a relatively sharp peak appears dominantly at the frequency of stimulation and a flat peak with its summit at the frequency of the control alpha peak leans to the left of the former in the shape of a hump. On the contrary, in the spectrum of the middle tracing (IIB1), the dominant peak is not located at the stimulating freqnency as it appears by visual inspection, but at a slightly higher frequency than the control alpha frequency, negating perfect synchronization with the stimulation, while the driven peak at the stimulating frequency forms a hump on the right of the dominant peak. Thus one should be aware of cases in which the dominant alpha wave in the EEG tracing during the stimulation is neither the driven wave itself, nor the purely irrelevant wave.

3) Evaluation by the Combined Method of Crosscorrelation and frequency Analysis.

In Figure 4, the alpha waves also appear to be well driven when visually inspected in the first half of the EEG tracings during the stimulation. No driven peak at the stimulating frequency, however, is suggested in the power spectra (IIA1 and IIB1), but only a dominant

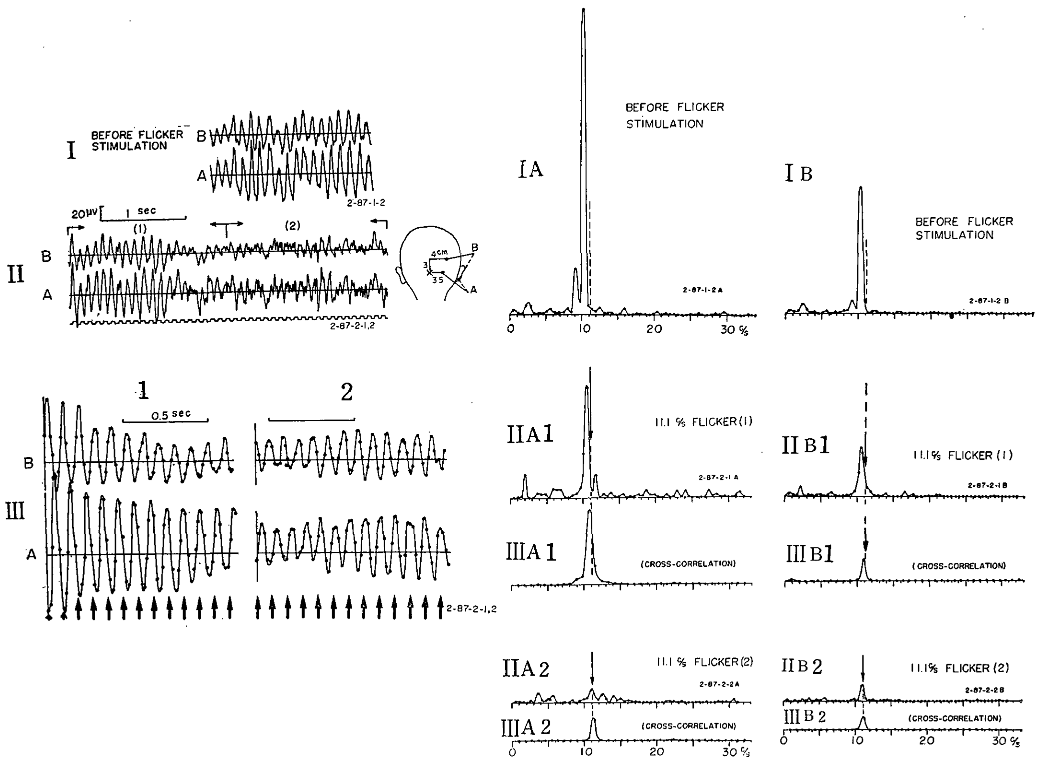

FIG. 4. A case of EEG response by photic flicker stimulation.
Left upper EEG tracings. I: Control tracings before initiation of the stimulation. II: EEG tracings approximately 15 seconds after initiation of the stimulation of 11.1 flashes per second (f/sec) indicated by the rectangular curve. The critical flicker fusion frequency of the stimulation was 12.5 f/sec.
Left lower curves III: Crosscorrelograms between the stimulation and the EEG in II. 1 and 2 computed from the first (II, (1)) and second (II, (2)) half of the tracing II respectively. The arrows pointing upward indicate the instant of flash delivery.
Right: Power spectra. IA and IB: The spectra of the control EEG A and B in I respectively. IIA1 and IIB1: The spectra of the former half EEG A(1) and B(2) in II during the stimulation.
IIA2 and IIB2: The spectra of the second half EEG A, (2) and B, (2) in II.
IIIA1 and IIIB1: The spectra of the crosscorrelograms II, A,1 and III, B,1.
IIIA2 and IIIB2: The spectra of the crosscorrelograms III, A,2 and III,B,2.
(See text)

peak rises at the control alpha frequency. In addition, its height becomes lower than the control height to suggest an inhibitory effect only. If the irrelevant waves in response to stimulation are eliminated, however, by taking the crosscorrelation between the stimulation and the EEG tracing, the driven waves are sorted out as illustrated in the crosscorrelograms (III,A and B) and in their power spectra (IIIA1 and IIIB1), a sharp peak with the stimulating frequency (11.1 c/sec) is separated. It is obvious, therefore, that this peak is fused in the peak of the control alpha wave with the frequeucy of approximately 10.5 c/sec, since the frequency difference of both peaks (approximately 0.6 c/sec) does not exceed the resolving power for frequency (approximately 0.5 c/sec) of the frequency analysis applied. Thus, not only an inhibitory effect upon the alpha wave in the relaxed control state, but an augmentative driving effect is also verified in the average frequency-pattern (power spectrum) of the crosscorrelogram between the stimulation and the EEG tracing.

From the above evidence, it is not always easy to evaluate exactly the EEG response in the power spectrum of the EEG tracing during the stimulation, especially when the driven peak is not separated clearly from other peaks to cause misjudgment as in the case illustrated in Figure 2. IIB1 and Figure 3.

In the power spectrum (IIA2) of the second half of the EEG tracing (Fig. 4, II (2)) at the level of inion, the peaks with the frequency of approximately 3.6 and 5.6 c/sec are seen in addition to peaks in the frequency ranging from 11 to 15 c/sec. The peak at approximately 5.6 c/sec appears to be a subharmonic response to the stimulation of 11.1 flashes per second, but this is not the case since it does not appear in the spectrum (IIIA2) of the crosscorrelogram. With the exception of the 3.6 c/sec peak and peaks in the frequency ranging from 11 to 15 c/sec in the spectrum (IIA2) of the tracing (IIA(2)) at the level of inion, most peaks are lower than those in that (IIA1) of the alpha dominant tracings (IIA(1)) of the first half. The same evidence is also shown in the spectra (IIB1 and IIB2) of other tracings. Thus, not only alpha-blocking, but beta-blocking is also suggested, notwithstanding the fact that the fast wave seems to be more enhanced in the tracings IIA (2) and IIB(2) than in those of the first half of the tracings IIA(1) and IIB(1). In the opening of eyes simillar evidence has already been demonstrated by MUNDY-CASTLE[19] and during continuous photic stimulation by Sato and MIMURA[30].

This alpha-blocking state demonstrated in Figure 4 seems to be caused by stimulation, since it occurred during stimulation. In the spectra of the crosscorrelograms, however, only a monomodal response peak is located at the stimulating frequency, indicating that the fast wave pattern is not a direct result of stimulation but may be other spontaneous activities.

Lately, STORM VAN LEEUWEN and BEKKERING[35] (1958) demonstrated evidence during eye closure that the alpha waves do not start at their dominant frequency, but at a higher frequency. Alpha waves with higher frequency may indicate cerebral activity similar to those in the alpha-blocking state, since eye closure would be preceded by some cerebral process to discharge the efferent impulses to the palpebral muscles. During photic stimulation, it would not be uncommon to precede with the same process even when the subjects' eyes are open.

In Figure 5, the average time-pattern of the EEG tracings during the stimulation (II) are shown by their autocorrelograms (IV), in which

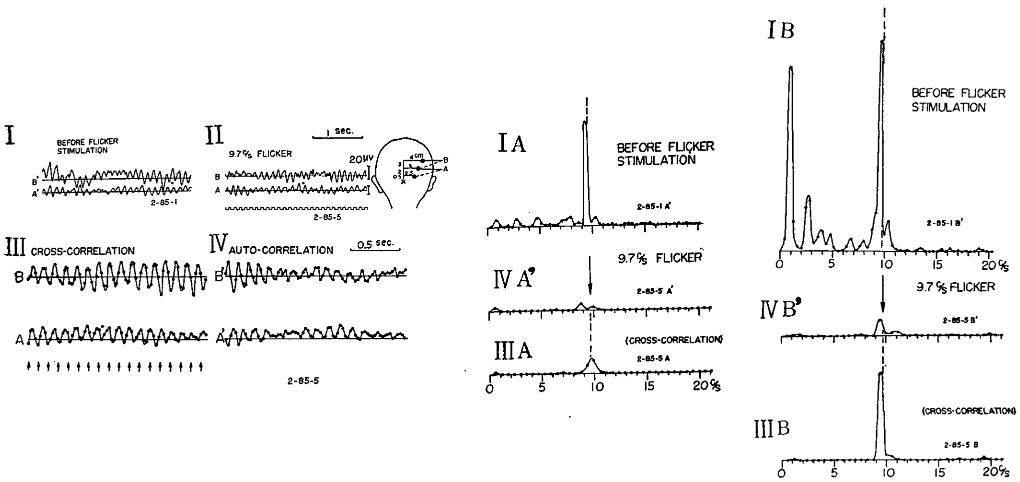

FIG. 5. Bimodal activity during photic flicker stimulation (green light).
I: Control EEG tracings without the flicker stimulation.
II: EEG tracings 60 seconds after the photic flicker stimulation with 9.7 flashes per second.
III: Crosscorrelograms between the stimulation and the EEG tracings during the stimulation.
IV: Autocorrelograms of the control EEG tracings.
IA and IB: Power spectra of the control EEG tracings (I).
IVA' and IVB': Power spectra of the autocorrelograms in IV.
IIIA and IIIB: Power spectra of the crosscorrelograms in III. The flicker fusion frequency of the stimulation: 11.5 f/sec.
(See text)

more regular waves than in the EEG tracings are plotted. They are waxing and waning which suggest a beat oscillation of the control and the driven alpha wave, since bimodal peaks in their power spectra (IVA' and IVB') are located at the stimulating frequency and at another point. It is noteworthy that notwithstanding the peak with a different frequency from the stimulation peak demonstrated in the previous paper (SATO, Ozaki et al.[34]) located at the control alpha frequency, here it is located at a lower position in the power spectrum of IVA' and at a higher position in that of IVB′ suggesting local differences in the cerebral activity between lower and upper occipital regions. In the crosscorrelograms (III) between the stimulation and the EEG tracings, however, the waxing and waning cannot be recognized. However, the oscillation lasts longer to indicate only a monomodal peak in its spectra with its greater height at the stimulating frequency rather than in the spectra of the autocorrelogram(Ⅲ A and Ⅲ B).

SUMMARY AND CONCLUSION

Some results of applying crosscorrelation and frequency analysis to normal adult EEG obtained before and during photic flicker stimulation demonstrate the average response time-pattern of the EEG tracing and reveal the average frequency-pattern more precisely than the EEG tracing itself.

By obtaining the fine structure of frequency spectra of the EEG tracings before and during flicker stimulation, average response frequency-patterns, which are impossible to evaluate by visual inspection of the tracings themselves, are sorted out. However, there are some cases in which the peak of driven waves is not separated in the fine structure of the frequency spectrum of the EEG tracing during stimulation. Even in these cases, the crosscorrelograms between the stimulation and the EEG tracing show a regular oscillation in the average response time-pattern. In its frequency spectrum, a monomodal peak is located dominantly at the stimulation frequency indicating the average response frequency-pattern.

Low voltage fast activity indicating alpha blocking is also observed during stimulation in the EEG tracings. In its power spectrum not only the peaks of fast alpha and slow rhythms but the peak with the same frequency as that of the stimulation is also obscured, while in the spectrum of the crosscorrelogram of the stimulation and the tracing only monomodal peaks appeared at the frequency of the stimulation suggesting that other peaks in the first spectrum is not caused directly by the stimulation.

A case of bimodal peaks in the power spectrum of the autocorrelogram of the EEG during the flicker stimulation is demonstrated. One of the peaks is located at the stimulation frequency but the other one is not at the frequency of the control alpha wave before stimulation.

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