PHOTIC DRIVING RESPONSE AND VISUALLY EVOKED RESPONSE IN EYE-OPENED STATE

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Since ADRIAN and MATTHEWS¹⁾ it has been shown that repetitive photic stimulation mostly derives cerebral rhythms at the alpha frequency. In the study of photic driving WALTER et al.^{2,3)} applied a frequency analyser with which the response was measurable in terms of the quantity of each frequency component. Moreover, the superimposition technique introduced by BARLOW⁴⁾ made it possible to detect the smaller, short-latency components of the somatosensory evoked response. With the aid of a computer averaging method, SATO⁵⁾ and KITASATO⁶⁾ observed that the amplitude of the evoked response to rhythmic flashes was maximal at the frequency of about 10 c/sec. The relationship between the visually evoked response and photic driving of the electroencephalogram was studied by KITASATO⁶⁾ who suggested that the driving responses were generated by the summation of the rhythmic after-discharge (so-called alpha-like waves according to his terminology) appearing on the late phase of the visually evoked response. He tried to explain in this way the mechanism of photic driving in eye-closed subjects. However, as is well known, the rhythmic after-discharge is not provoked in the subjects with eyes opened. It is considered, therefore, that the hypothesis of Kitasato is not sufficient to explain the fact that photic driving occurs even in the eye-opened state, and that another component of the evoked response may be related to the generation of photic driving.

The investigation which is reported here was made for the purpose of finding the relationship between the visually evoked response and driving response to rhythmic flashes in the eye-opened state.

METHODS

The observations were made on 42 healthy human subjects who were screened for visual acuity (1.0-1.5) and for gross neurological normality. Their ages ranged from

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17 to 57 years. Twenty nine of the subjects were male and 13 were female. Each experiment was performed in a dimly lit and relatively sound proof room with the subject lying in a supine position.

The photic stimulus was transmitted from the lamp fixed in a position approximately 30 cm away from the subject's opened eyes. The intensity of the flash light was one joule as an electric energy provided to a xenon gas stroboscope. The flash frequency was varied from 1 to 30 c/sec. One series of rhythmic photic stimulation was carried out for 30 seconds, with an interruption period of one minute.

Each subject had been previously instructed to fix his gaze on the lamp and never to blink during a train of flash stimulation.

Bipolar recordings were made from the occipito-ventral derivation with an ink-writing oscillograph. Negative potentials at the occipital electrode produced an upward deflection on the tracing. Sometimes ventral monopolar recordings were made in order to ascertain whether photic driving occurs in the ventral region. The stimulus signals delivered from an electronic photic stimulator were recorded simultaneously with the EEG. The average evoked response to flashes was obtained by means of a digital computer MEDIAC (MC-401, San-ei Sokki Co. Tokyo) from the same electrodes as for EEG recording. For each, 50 responses were averaged. Analysis time was 250 msec in most cases, but occasionally 0.5 or 1.0 second. The recovery function of the average evoked response was studied by paired stimuli, with the intervals between conditioning and test stimuli varied systematically between 10 msec and 500 msec. Four subjects who gave good photic driving in the awaking state were selected for sleep studies.

Certain problems arise in measurement of the amplitude of the driving response. In the present experiment the peak to peak amplitude of the fundamental responses, which were locked in phase to the flash frequency, was measured with a visual method of analysis. Harmonic or subharmonic response was not taken into consideration.

RESULTS

(1) *EEG responses to flashes*

Of all forty two subjects, 15 responded at the fundamental to a wide frequency range of photic stimulation (35.7%). In the remaining 27 subjects no photic response could be detected. No photic driving was observed in any subject employed for sleep studies. No driving response appeared on the ventral monopolar lead. In FIG. 1 are illustrated the typical EEG records showing the marked photic driving. In about a half of the subjects the synchronization of the response was incomplete in first 0.5-1.5 sec. during a flash series. This was noted particularly at frequencies higher than 6 c/sec (FIG. 1-1, 3). In the favorable subjects synchronization with the flashes was found throughout a sequence of photic stimulation, although the response began maximally with the first flash of series (FIG. 1-1, 4). There was no significant waxing and waning of the response in most subjects who gave photic driving. However a transient absence of the response, as seen at 15.6 and 23 c/sec in FIG. 1-1, 2, was observed occasionally.

FIG. 1. Sample records of photic driving. Each column (1-4) was obtained from four different subjects. Note the maximum amplitude of the response at 7-8 c/sec in 1, 2 and 3, and gradual decrease of response amplitude in 4.

A; control EEG in eye-closed state before photic stimulation.

B; EEG and photic driving in eye-opened state.

In this and all subsequent figures numbers on the left side of each record indicate stimulus frequency except those in FIG. 7.

FIG. 1: 3. 4

FIG. 2 shows the frequency-response curves obtained by plotting the arithmetically averaged amplitude of the fundamental response during the complete period of photic driving. The fundamental response profiles could be divided into two principal types. In the first type, shown in FIG. 2-a, b, c, d, the response amplitude increased with the stimulus frequency up to a peak at 7-8 c/sec and then diminished progressively. In the second type, as shown in FIG. 2-e, f, the response amplitude was maximal at 1 c/sec and decreased with an increase in frequency in an approximately linear fashion. These first and second types will be referred to as "summation type" and "non-summation type" respectively. Of fifteen subjects who showed photic

FIG. 2. Plot of arithmetically averaged frequency-amplitude values for fundamental responses obtained from the same subjects as in FIG. 1. Curves a, b, c, and e correspond to 1, 2, 3 and 4 in FIG. 1 respectively.

The solid lines (a, b, c, d) are "summation type" showing maximum at 7-8 c/sec, and the broken lines (e, f) are "non-summation type" showing gradual reduction in amplitude with the increase in stimulus frequency.

driving, eight belonged to the former (55.5%), and seven to the latter (44.5%).

(2) *Average visually evoked response to flashes*

Major features of the response to a single flash were consistent from individual to individual, although there were inter-subject differences in the relative amplitudes and peak latencies of various response components. One sample record is shown in FIG. 3. The initial positive wave described by

FIG. 3. Typical average evoked response representing seven deflections. In this and following figures, negativity at the occipital electrode is recorded upward, and photic stimulation is presented at the beginning of the record.

COBB and DAWSON⁷⁾ could not always be detected in any subject. The response was divided into seven components for the convenience of description. This division does not mean that each component necessarily represents a physiological process of the underlying mechanism. The mean latencies of components I, II, III, IV and VII were 32, 45, 68, 92 and 170 msec. respectively. The longer the latency of each component was, the greater was the standard deviation of the latency. In some subjects components I and II were not detected, but component III was always observed in all subjects in spite of a considerable inter-subject variability of the amplitude. In a sequence of components IV-VII, IV and VII were reproducible and steady in all subjects,

but there were some subjects who failed to produce V and/or VI.

The average evoked responses to various rhythmic flashes are shown in FIG. 4. In column A components I, II, III and VI are not clear at 1 c/sec, while components VI and VII are clearly observed. The response to a single

FIG. 4. Sample records of averaged evoked response to rhythmic flashes. A and B were obtained from the same subjects as in 1 and 4 in FIG. 1 respectively. Note the amplitude of component VII enhanced maximally at 7 c/sec in A and decreasing successively in B.

flash appears separately at less than 5 c/sec. At more than 6 c/sec the response to each single flash overlaps each other and the shape of the response becomes sinusoidal with the maximum amplitude at 7 c/sec. In column B the early components I-III are clearly observed at 1 c/sec and remain almost unaltered up to approximately 10 c/sec. On the contrary, the late components V-VII become successively smaller with an additional increase in stimulus frequency.

FIG. 5 shows the frequency-response curves of component VII obtained from the records in FIG. 4. The solid line is similar to curves a, b, c, d in FIG. 2, and the broken line to curves e, f in FIG. 2. These similarities suggest that there is a close relationship between each fundamental constituent

FIG. 5. Plot of peak-peak amplitude of component VII. Solid line and broken one were attained from A and B in FIG. 4 respectively.

of the driving EEG response and component VII of the average evoked response. However, the early deflections, especially component III, are related to some extent to the driving (FIG. 6). Moreover, the early deflections are discerned until the response deforms to sinusoidal (FIG. 4, B).

FIG. 6. Average evoked response to rhythmic flashes. It is noted that the main component locked to each flash frequency is VII. Component III indicated by an arrow mark is very small in comparison with VII, and simply superimposes on VII at more than 6 c/sec.

(3) *Recovery function of component VII.*

Four subjects were selected for this study. Paired stimuli were applied to the opened eyes. Series of records from two subjects were illustrated in FIG. 7. The measures of component VII were peak to peak. At inter-stimulus intervals less than 40–60 msec. there is no apparent response to the test stimulus. The component III of the response to the test stimulus becomes distinct at about 60–80 msec. interval and reaches maximum amplitude between 120–190 msec. At this maximum, the response is facilitated, being approximately 1.3–1.5 times higher than the same wave for the conditioning stimulus. The excitability cycle gave an inverted U-shaped recovery (FIG. 8).

FIG. 7. Average evoked response to paired stimuli,

S; response to single flash.

D; response to double flashes.

A and B were obtained from the same subjects as in 1 and 4 in FIG. 1 respectively. Numbers on the left side of each record indicate the interstimulus interval in msec.

FIG. 8. Recovery function of component VII expressed in the usual manner as the ratio of amplitude of test response to that of control response. Solid line and broken one were attained from the same subjects as in 1 and 4 in FIG. 1 respectively.

DISCUSSION

There are numerous experimental results which suggest that the background EEG activity is closely related to photic driving. TOMAN⁸⁾ and ADRIAN⁹⁾ demonstrated that rhythmicity and amplitude of the photic response were most marked at the frequency of the spontaneous alpha rhythm. A similar relation was observed by MUNDY-CASTLE,¹⁰⁾ who assumed that a significant relationship between the existence of spontaneous alpha rhythms and driving of the response at these frequencies was attributable to a resonance effect involved in the cortico-thalamic circuit. From the results of these workers one may expect a common neural mechanism between the photic response and spontaneous alpha activity. On the other hand, WALTER and WALTER³⁾ noted that the photic response and the alpha rhythm did not originate from the same cortical areas. If the spontaneous background EEG shows a high voltage activity, it seems difficult to identify the evoked re-

sponse from the spontaneous rhythm. This difficulty might be overcome in the way that the spontaneous rhythm is kept at low voltage and fast. Thus in the present experiment photic stimulation was provided with the subjects eyes opened, in order to make the background EEG activity fast.

As TOMAN⁸⁾ already pointed out, it is obvious that photic driving is a succession or a modality of the visually evoked responses. CIGÁNEK¹¹⁾ divided the human visually evoked response into three complexes; the primary response (I-III) involved in the specific visual pathway, the secondary response (IV-VII) involved in the non-specific diffuse pathway, and the rhythmic after-discharge. Our interest in this study is to find how these three complexes relate to the provocation of photic driving. In the eye-opened state rhythmic after-discharge is not seen in the evoked response, thus making it difficult to relate the after-discharge to photic driving. Our present findings show that although both the primary and secondary response relate to photic driving of the EEG, the main constituent of the driving response in "summation type" is the secondary response, especially the long latency component labelled VII. However, if the primary response designated I-III is large in magnitude in comparison with the following secondary response, it also may take an important part as the constituent of the driving response. This assumption might be attributable to "non-summation type" shown in FIG. 4, B. The critical frequencies for deforming the evoked response sinusoidal are variable depending on the duration of the response to a single flash. As the duration of the evoked response is 100-190 msec. in most subjects, it is expected that the critical frequencies are approximately 5.2-10 c/sec. Summation of the response is observed in this frequency range especially at 7-8 c/sec. It is considered to be theoretically reasonable that the responses are never augmented at more than 10 c/sec, and excitability of component VII does not recover at less than 100 msec in interstimulus interval of paired stimuli. Therefore, it seems likely that the primary response contributes mainly to photic driving at more than 10 c/sec.

The mechanisms of component VII are not of primary concern here, but it must be emphasized that VII is probably analogous to a vertical potential described by DAVIS^{2,3)} and LARSSON.¹⁴⁾ DAVIS et al. related the on-effect to the slow part of the K-complex seen during sleep and showed that visual, auditory or somatosensory stimulation also could provoke this potential. GASTAUT¹⁵⁾ and BANCAUD et al.¹⁶⁾ have found that this potential is largest at or near the vertical region. It has been established by these workers that the vertical potential is variable in latency (40-200 msec) and requires 0.3 to several seconds for complete recovery. However, in the experiment carried out here, the latency and recovery time of component VII are 100-190 msec and 120-170 msec respectively. Moreover, photic driving scarcely develops in the sleep state, and is dominant in the occipital visual area. Thus component

VII might be one of the secondary response different from the vertical potential or K-complex.

SUMMARY

1. Photic driving of the EEG and the average evoked response to photic stimulation were studied on 42 normal subjects between the ages of 17 and 57. Photic stimulation was applied during the period of suppressed EEG, while the subjects kept their eyes open.
2. Marked photic driving was observed in 15 subjects (35.7%). The frequency response curve, showed two types of response pattern. The one was "summation type" which showed the maximum amplitude at the stimulus frequency of 7-8c/sec. The other was "non-summation type" which showed a gradual decrease in parallel with frequency increase.
3. The frequency response of the average evoked response produced the same course of events as that of photic driving.
4. The negative component of the evoked response with the peak latency of 170 msec showed maximal percent recovery at 120-190 msec. interval of paired stimuli.
5. It was suggested that the most indispensable component of the evoked response was VII, one of the secondary response, for the generation of photic driving in the eye-opened state.

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