ON THE EVOKED MASS-POTENTIAL IN RELATION TO ELECTRICAL BACKGROUND ACTIVITY IN THE RABBIT

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Many studies have been carried out on the role of the non-specific system in the generation of cortical evoked reactions. The results that have been obtained are very complicated and the effects of non-specific activity on the sensory informations have been reported augmentative, depressive or indifferent. In the present study, an attempt was first made to determine the changes in induced activity of many cortical and subcortical structures (Mimura and Sato, 1965; Mimura et al., 1967) in relation to background cerebral activity levels. Next, the relationship between changes in the above activity and the regular synchronous EEG waves of 3-5 up to 5-7 sec due to enhanced tonic reticular activity, which are characteristic in various cortical and subcortical structures except in the motor cortex of rabbit (Gangloff and Monnier, 1956; Monnier and Gangloff, 1961), was studied because of the resemblance in their frequencies.

METHODS

The preparations, experimental apparatus and procedures were almost the same as those used in the previous report (Mimura et al., 1967). The additional use of an analogue type correlator (CCA-22, Sony Corp.) was made for obtaining autocorrelograms of EEG recorded on 1/4 inch magnetic tape was played back and re-recorded on 1/2 inch endless magnetic tape for 35 sec. The autocorrelogram was automatically written through the correlator, which can analyse wave forms in frequency range of lower than about 20-30/sec, and the time delay of one step was 12.5 msec.

RESULTS

1. Effects of arousal state on response to flash depicted in the autocorrelogram. In Fig. 1A, the so-called sleep pattern (Monnier and Gangloff, 1961)
Fig. 1. EEG tracings under various conditions during 1/sec flash stimulation.

A: Sleep pattern with irregular slow waves in every EEG. Sometimes spindle waves appear in the motor cortex (Mc). B, D and E: Arousal EEG pattern with regular synchronous waves except in Mc and OR caused by high frequency stimulation to reticular formation (RF) (B), electrical stimulation to right hindlimb (D) and by standing a man near the animal (E). C: Immediately after cessation of the reticular stimulation. EEG configurations in Mc and OR change to low amplitude, fast pattern by arousal. Lowest tracings denote flash stimulation. Upward deflection is negative in all tracings. Calibration: 100 μV. Time scale 1 sec.
was seen in the irregular EEG waves of the limbic cortex (Lc), visual cortex (Vc), optic radiation (OR, 2 mm beneath cortical surface) and lateral geniculate body (GL) as well as in the spindle waves of the motor cortex (Mc), whereas

![Diagram](image)

**Fig. 2.** Three cases of effects of arousal on the evoked potentials.

F: flash stimulus only during sleep EEG, F+RF: flash during arousal state by high frequency RF stimulation, F aft.: flash immediately after cessation of RF stimulation, F+Cut.: flash during arousal by electrical cutaneous stimulation, F+Man: flash during arousal by a man standing near the animal. Each potential was summed up thirty times by ATAC. Analysis time: 500 msec. Calibration: 100 μV. During arousal, each component of the evoked potential to single flash was reduced as compared with that by flash only during the sleep state (see Fig. 1A), whereas no changes were observed in ERG.
Fig. 3. Autocorrelograms (X) of EEG in OR during sleep (1F) and arousal patterns (other four curves of X and Y) and signal to noise ratio curve (Y) in relation to time.

Jutting waves on autocorrelograms correspond with the evoked potential by 1/sec flash. Abbreviations see Fig. 2. During sleep EEG, responses were irregular in size and noise component was very large, while during arousal they became regular with reduced noise.

Y: Signal (evoked potential) to noise (background activity) ratio (S/N) curves. Amplitudes at the time origin were taken as 100 and relative amplitudes of each response were plotted as time series.

Time scale for X 1 sec.
the arousal pattern of EEG due to various irritable conditions was seen in B, D and E. Photically induced response were markedly deteriorated in the arousal state (Fig. 1B and D). The same effect was produced in every component of the evoked potentials irrespective of the condition eliciting the arousal, though some variations are seen (Fig. 2). In such averaged patterns, however, the time course of the effects cannot be elucidated. Therefore, autocorrelograms of EEG during 1/sec flash stimulation were obtained under the above conditions (Fig. 3X) and also of those during 1 and 3/sec flash stimulations were obtained under the background activities of natural sleep and arousal state (Fig. 5X). The repetitive swells and troughs of the stimulating frequencies in the autocorrelograms of EEG during sleep differed from each other (Fig. 3X 1F; Fig.

![Autocorrelograms of EEG during 1/sec flash stimulation.](image)

**FIG. 4.** EEG tracings (A) and average responses of OR to flash (B) in sleep (s) and natural arousal (a) during 1/sec (1F, 1 fps) and 3/sec (3F, 3 fps) flash stimulations.
Fig. 5. Autocorrelograms (X) and signal to noise ratio curves (Y) of EEG tracings from OR during sleep (s) and natural arousal (a) in Fig. 4.

X: S and A are natural sleep and arousal patterns respectively. Marked swells are evoked responses to flash.

Y: reduction of noise element and increase in regularity of response amplitudes during arousal are distinct.

Time scale for X 1 sec.
to show irregular patterns in the EEG. Those during arousal, however, were almost consistent (Fig. 3X 1F+RF, 1F aft., 1F+Cut., 1F+Man; Fig. 5X A.) It was found, therefore, from the autocorrelograms of EEG during 1 and 3/sec flash stimulation that the responses to flash during sleep are irregular in time-course but those during arousal are regular.

As previously demonstrated in autocorrelograms of human EEG during rhythmic flash stimulation by SATO and KITAJIMA (1965), the oscillation configuration with the stimulating frequency first decayed in their amplitude after which they continued at a constant size. This pattern is identical to the autocorrelogram of a random process where repetitive signals of constant size are contaminated by a random noise, which appears as a decaying configuration in the autocorrelogram (LEE, 1950). Here, the more prominent the deterioration of the amplitudes in the autocorrelogram is, the more irregular is the EEG. The arousal effects can, therefore, obviously be demonstrated by taking a tracing of the relative amplitude of swells in the autocorrelogram, in which the amplitude at the time origin (time delay $\tau=0$) is taken as 100 on the ordinate and time in sec is taken on the abscissae (FIG. 3Y and 5Y). It is evident from the diagrams that decay of the curves was more marked in the case of only 1/sec flash (Fig. 3Y), and in the sleeping state (FIG. 5Y, sleep) as compared with the arousal state (lower four diagrams of Fig. 3Y and arousal of Fig. 5Y), because the curves in the sleeping arousal states settle down respectively to a level of less than 50 and to that of about 60. The amplitude at the time origin ($\tau=0$) in an autocorrelogram indicates the amount of variance (square of standard deviation) in the fluctuations due to the signal (response to the stimulation) and noise (spontaneous background activity) in the EEG record, whereas the amplitude when it has settled down to a fixed level indicates mainly that of the signal. Let here, therefore, the variance caused by the signal and noise be $S$ and $N$ respectively, and further the fixed level in the above amplitude diagrams in Fig. 3Y and 5Y be $100L$. Then $L$ can be expressed in the following form, i.e.

$$L=\frac{S}{S+N}=(S/N)(1+S/N)^{-1}=S/N-(S/N)^2+(S/N)^3-\cdots$$

Since $S/N$ is less than unity,

$$L=\frac{S}{N}, \quad (S/N<1)$$

for the first approximation. Then $L$ may be regarded, for the first step, as the signal-noise ratio and the curves in Fig. 2Y and 5Y are $S/N$ curves.

Hence, the above would suggest that a higher $S/N$ ratio (signal-noise ratio) in sensory information process will be brought out by a higher tonus in the midbrain reticular formation (RF) during the arousal state. As shown in Fig. 5Y, the $S/N$ curve of 3/sec in the sleeping state showed irregular fluctuations, while it was more flat in the arousal state. This fact indicates that rise in the RF tonus is accompanied by increase of regularity in the sensory signals.
Fig. 6. EEG patterns with respect to brain activity levels.

s: Sleep pattern. All tracings are irregular desynchronized pattern, and spindle waves appear in Mc. a: Arousal pattern. All tracings are regular synchronous “theta” waves except in Mc where there is low amplitude pattern.
s-a: Mixed pattern of s and a. This state was changeable between both a and s.
Fig. 7. The response amplitude-frequency diagrams in OR, Vc and Lc to GL stimulation during sleep (s), arousal (a) and the mixed EEG patterns (s-a).

Amplitudes and stimulating frequencies were taken respectively as ordinates and abscissae. Scale only was indicated when the response was too small to measure.

I, I₀, I', II, III and IV: Wave components. Accompanying change from s to a, peaks were augmented and concentrated at one or a few frequencies.
2. Relationship between background EEG and the activity changes in the specific and non-specific components. In the previous paper (Mimura et al., 1967), the activity originating from the specific and non-specific systems in various structures were investigated. Here, the effects of the background activities on the activity were studied. The background EEG was roughly divided into three classes, as shown in Fig. 6: sleep (s), sleep-arousal (s-a) and arousal pattern (a). In the sleep pattern, slow desynchronized waves were dominant in every recording site and spindle waves appeared sometimes in MC. In the arousal pattern, regular synchronous waves appeared in every tracing except for low amplitude waves in Mc. In the sleep-arousal pattern, characteristics of both sleep and arousal patterns were intermingled. Characteristic activities originating from the specific and non-specific systems respectively were observed in relation to background EEG activities.

![Diagram](image)

**Fig. 8.** The response amplitude-frequency diagrams in GL, Vc, OR and Lc to RF stimulation during sleep (s), arousal (a) and mixed EEG patterns (s-a). Abbreviations see Fig. 7. No data during sleep (s) stage of GL was obtained. With change of background activities from s to a, peaks were reduced and remained multimodal.
FIG. 9. The response amplitude-frequency diagrams in GL, Vc, RF, OR, Lc and CS (superior colliculus) to repetitive flash stimulations.

Frequencies of flash were taken as abscissae. There was no data in s of CS. Considerable variabilities and complications appeared in the diagrams with change of background EEG.
A. Activity originating from the specific system. Augmented activities in response to GL stimulation were brought out similarly in every recording site at 3-4 to 7-8/sec in the early potentials (FIG. 7, I in OR, Vc, and Lc; Io in Vc; II in OR), at 4.5-5.5/sec in the potentials that followed (III in OR and Lc; I' in Vc; II in Vc) and at 3-3.5/sec in the late potentials (IV in OR and Lc; II in Vc) (MIMURA, et al., 1967). As shown in FIG. 7, none of the peaks appearing in the sleep and sleep-arousal patterns were outstanding, whereas only one or two predominant peaks were enhanced in the arousal pattern. In addition, the amplitude-frequency diagram of each response component, except the late one, showed the highest amplitude in the arousal state. These findings indicate that the above augmentations become accelerated and predominant as the background EEG shifts from sleep to arousal pattern.

B. Activity originating from the non-specific system. Contrary to GL stimulation, shift of background activity from sleep to arousal generally produced a decrease in size of the potentials due to RF stimulation (FIG. 8). The marked peaks in the sleep pattern decreased (I and I' of GL, II and II' of Vc, I and II of OR and Lc) or even disappeared (I of Vc) in the arousal pattern, but moreover the amplitude frequency diagrams themselves were lowered.

C. Flash response. The changes in the flash responses were far more variable than those in the above two with shift of background EEGs from sleep to arousal patterns (FIG. 9): (i) GL stimulation-like effect, in which the response pattern was concentrated into one or two frequencies and the amplitude of responses was generally augmented (B and B' of OR; B' and C of CS), (ii) RF stimulation-like effect, in which the amplitudes of responses were generally lowered and the marked peaks were split into several small peaks (A of GL; A and C of Vc), (iii) Partly GL stimulation-like effect, in which one of the above GL stimulation effects was observed (C of OR; A and A' of CS), (iv) Partly RF stimulation-like effect, in which one of the above RF stimulation effect was observed (B and C of GL; A and B of RF; A of OR), (v) Mixed effect of GL and RF stimulation, in which one peak was augmented but others were lowered (B of Vc and Lc), one peak remained but amplitudes were generally lowered (A of Lc), amplitudes were generally increased but many peaks appeared (C of RF) or amplitudes were generally increased but many peaks remained (C of Lc).

3. Behavior of evoked responses to repetitive flash stimulations and that of repetitive algebraic summations of the evoked potential to single flash stimulus. It is evident from not only the finding described above but also from previous observations (MIMURA and SATO, 1965; MIMURA et al., 1967) that the frequency of spontaneous EEG waves of rabbit cerebral cortex during arousal closely resembles that of augmentation in the evoked response activities. The cerebral evoked responses brought out by repetitive flash stimulations of various frequencies and the repetitive algebraic summations of a single flash response were...
FIG. 10. Evoked potentials in response to repetitive flash stimuli of various frequencies and repetitive algebraic summations of evoked potential to single flash stimulus of the same frequencies as that of stimulations.

A: Evoked potentials (left column) to repetitive flashes of various frequencies (numerals on left side) which were obtained as average forms of ten responses by the simplified method (SATO et al., 1962) from tracing by bipolar frontal-occipital lead. Right column shows the wave forms of algebraic summations of single flash responses at the same repetitive rate as the flash frequencies. Both configurations were very similar to each other, and those at 4-6/sec were roughly sinusoidal and resembled spontaneous regular waves. Vertical lines beneath each wave are signals of the flash stimulation.

B: Amplitude-frequency diagrams of repetitive flash responses (white circles) and repetitive summations (filled circles).

Both diagrams have similar tendency in general, but some differences are evident such as that repetitive flash response activities are augmented by 3 and 6/sec stimulations, but depressed by stimulations of more than 8/sec.
compared at the same frequencies in the unanesthetized, unrestrained rabbit (Fig. 10). Both wave forms at each frequency were very similar suggesting that the configuration of repetitive flash evoked potentials may be obtained from the algebraic summation of single flash responses. In addition, a sinusoidal wave form was obtained by 4-6/sec stimulations and summations. However, their amplitudes did not coincide with each other, the repetitive flash evoked potentials being higher at 3 and 6/sec and lower at stimulations of more than 8/sec in comparison with the algebraic summated potentials (Fig. 10B). Thus, augmentative and depressive interactions respectively were exhibited by these repetitive stimulations. Therefore, if activities at these augmentating frequencies were to continue, a sinusoidal wave form of the above frequency will be sustained consisting mainly of the slow component of the evoked potential (component C).

**DISCUSSION**

Although very many investigations have been made concerning the effects of background activity on the sensory informations (cf. Narikashvili, 1963; Buser, 1964), the results were not necessarily consistent. In this report, these effects were studied by autocorrelograms and "response amplitude-frequency diagrams", i.e. the activity changes in relation to stimulating frequencies described previously (Mimura et al., 1967).

As shown in the autocorrelograms of EEG during flash stimulation, noise elements with respect to signals (evoked potentials) were decreased and large, regular sensory signals were induced when the brain fell into the arousal state. Taïra and Okuda (1962) demonstrated an increment of the stability of unitary and mass responses in the lateral geniculate body and visual cortex of cat to localized visual stimuli during the alerted state. These evidences suggest that the sensory informations increase in acuity with rise of the brain activity level.

The observations have been somewhat variable concerning the influences of the excitatory level of the brain on the responses to single electric stimulus of sensory pathways. Favale et al. (1965) demonstrated that the amplitudes of the somatic response in the nucleus ventralis posterolateralis were maximum during deep sleep but inconstant during arousal, and that those in the cortex were maximum during light sleep but depressed during deep sleep and arousal. Allison (1965) found that the responses in the somatic cortex to stimulation of ventrobasal complex were higher in "slow" sleep than in wakefulness, whereas the responses in the ventrobasal complex to stimulation of the medial lemniscus were higher in wakefulness than in "slow" sleep. Furthermore, in the visual system also, a reticular or sensory arousing stimulation produced an increase in size of the cortical potential evoked by an electrical shock to the thalamic relay nucleus or optic nerve (Bremer and StoupeL, 1958) or to the optic chiasma (Dumont and Dell, 1958, 1960). In addition, the cortical evoked
responses to repetitive electrical stimulation of the optic tract or lateral geniculate body was greater and more regular during arousal induced by high frequency reticular or cutaneous stimulation (NARIKASHVILI, 1963). However, some findings to the contrary have been observed on the arousal effect on the augmenting response. GAUTHIER et al. (1956) demonstrated a prominent reduction of the augmenting responses by stimulation of somatosensory relay nuclei during arousal, whereas NARIKASHVILI (1963) observed a marked enhancement of these responses by stimulation of lateral geniculate body during this state. The results of this paper coincided with some of the many investigations mentioned above but not with others. Detailed, systematic findings were elucidated by using the "response amplitude-frequency diagrams" with respect to the arousal and sleep effects. Generally speaking, change of background activity from sleep to arousal was accompanied by accentuation of every component of the responses in the cortical areas to lateral geniculate stimulation and, especially, the activities to stimulation at one or few of the frequencies only were exclusively strengthened. This tendency of concentric acceleration by arousal is analogous with the findings of FREEMAN (1961, 1962a, 1962b) that the "frequency-response-amplitude curve" of the primary olfactory cortex or the prepyriform cortex of cats obtained by stimulations at various frequencies to this cortex itself or to the lateral olfactory tract shows a rise at one frequency in which a relatively sharp peak was formed during the attentive state of the animals, while this peak was reduced and became very broad in the inattentive or habituated state. Although the stimulating and recording sites as well as the peak frequency and animal differed from those in our data, the tendency of concentration and acceleration is common to each in the transmissions of sensory signals via the specific pathways during arousal or the attentive state. This tendency indicate that there is an increase of regularity in sensory signals during arousal as mentioned on the basis of SATO et al.'s deduction (1961) and it seems that the irregular and random or unnecessary sensory inflows are eliminated while the regular or necessary ones are exclusively permitted to flow into the higher center during higher brain activity.

When viewed in relation to the background activity, the cortical and lateral geniculate responses to repetitive low frequency stimulation of the reticular formation showed a tendency which was opposite to that in lateral geniculate stimulation. ALLISON (1965) described the "secondary" response to single stimulation of reticular formation as being markedly higher in amplitude during "slow" sleep than during wakefulness. Not only were similar results, but also more precise findings were obtained in this paper too. As seen in the "response amplitude-frequency diagram", with change of background EEG from sleep to arousal, responses to stimulation of reticular formation were not only reduced in every component from each recording site but also did not show the rising up of any conspicuous peak. Nevertheless, arousal is usually considered to be
increase of RF activity, and the above findings seem to be paradoxical with this. However, in addition to the activating action of the reticular formation, (Moruzzi and Magoun, 1949), a deactivating function during arousal has recently been postulated for this site by Moruzzi (1964). Thus the above paradoxical phenomenon may be explained if the flow of impulses into higher centers from this structure were to be at such a low frequency activity which can produce the deactivating action.

The effects of high tonus of the reticular formation on peripherally induced responses are reported to be more variable than those due to electrical stimulation to sensory pathways, and even results to the contrary have been demonstrated by some authors. Amplitudes of cortical evoked potential by single click were higher in wakefulness than sleep (Chin et al., 1965), while those by single flash were depressed in arousal (Bremer and Stoupe, 1959; Narikashvili, 1963). By using intermittent light stimulation, Steriade and Demetrescu (1960) found that the amplitudes of the response to light in the lateral geniculate body were increased at every frequency of light used in high frequency stimulation of the reticular formation whereas those in the visual cortex were reduced by light delivered at frequencies of less than 3/sec and increased by those of 5-20/sec. Narikashvili (1963) also has observed depression of the cortical primary response by 3/sec flash and augmentation by 5-6/sec during high frequency stimulation to the reticular formation.

These findings were partially verified in our “amplitude-frequency diagrams” of each response component, though some complicated features were observed in all recording sites. With change of background activity, however, some response activities were augmented, whereas others were depressed. Bremer and Stoupe (1959) explained the paradoxical inhibition as “masking”, in which the effect of arousal on the evoked response to stimulation of the peripheral receptors was inhibitory in general, whereas augmentative in stimulation of the sensory afferents. However, the complicated effects mentioned above can not be understood completely but only partially by such an explanation. It seems rather reasonable to assume that the activities in the “response amplitude-frequency diagram” produced by lateral geniculate stimulation may depend mainly of the specific systems whereas those by stimulation of the reticular formation rely on the non-specific ones, while sensory stimulation applied to the peripheral receptors may produce a linear and/or non-linear admixture of both activities. It is recognized, therefore, that the activities elicited by repetitive flashes are complicated, being either depressed or augmented, and show a mixture of tendencies of concentrical acceleration and irregular depression brought out respectively by GL and RF stimulations. At such time, the neuronal control with respect to these mixed and/or additive activities may be performed by the reticular structures as suggested by Hernández-Peón (1961).
The regular cortical waves during arousal are well known to be very similar in frequency with hippocampal arousal waves. Petsche and Stumpf (1960) have suggested that the spontaneous regular wave was that by physical spread from the septal pace maker. However, since the EEG tracing of the optic radiation (OR, immediately beneath the cortical surface) in Fig. 1 and 2 showed no regular wave, their opinion does not adequately explain the origin of cortical regular waves. OR beneath the cortical surface is the region of "null" and the regular waves of surface and depth regions are out of phase with each other. Deducing from the similarity of the wave forms shown in Fig. 10 and the concentrating-accelerating tendency in the arousal state, it was suggested that the spontaneous regular EEG may perhaps involve the slow late component of the evoked potential at least in part, although further direct demonstrations are necessary on the participation of the same neuronal elements in both waves.

SUMMARY

The relationships between the response configurations of evoked potentials and background EEG activities were investigated from the autocorrelogram and "response amplitude-frequency diagram" by using unanesthetized, immobilized rabbit.

Autocorrelograms of EEGs in the arousal state during repetitive flash stimulation showed an increase of regularity and decrease of noise elements in the amplitudes of the evoked potentials. This elevated brain activity level means the increased acuity and clarity of sensory informations.

From the response amplitude-frequency diagram during repetitive lateral geniculate (GL) stimulation, the concentrating-accelerating tendency by arousal were evident in the activities of specific origin. That is to say, with change in the background EEG from sleep to arousal, every component of the cortical potentials evoked by GL stimulations of various frequencies were augmented and especially the responses to only one or two stimulating frequencies were found to show a concentrating increase. These frequencies correspond to the characteristic frequency in the specific system demonstrated in the previous paper (Mimura et al., 1967). On the other hand, the responses to repetitive reticular (RF) stimulations of various low frequencies retained their irregularity in the response diagrams and, contrary to GL stimulation, their amplitudes were decreased due to arousal EEG. Peripherally induced responses to repetitive flash stimulation exhibited a very complicated behavior in their augmentative and depressive tendencies with change of background EEG, suggesting mixed or summated features due to both augmentative specific activities (by GL stimulation) and depressive non-specific activities (by RF stimulation).

The spontaneous regular EEG wave in arousal was discussed from the
resemblance of frequencies in relation to the activity changes of the evoked potential.

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