GENERAL AND LOCAL CHANGES IN THE ELECTROENCECPH-ALOGRAM DURING THE FORMATION OF CONDITIONED MOTOR REFLEXES IN MAN

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The method of electroencephalography is being used on an ever widening scale in the investigation of higher nervous activity. Many researchers have shown that conditioned reflex changes in the α-rhythm may be obtained. The conditioned reflex depression of the α-rhythm obtained by a combination of sound and light has been studied by Durup and Fessard [9], Loomis, Harvey and Hobart [11], Jasper and Shagass [10], P. I. Shpil'berg [8], and others.

It has been shown that a conditioned reflex reorganization of the cortical rhythm can be obtained in man by the action of a rhythmic light stimulus [4, 6]. Changes in the electrical activity in the cortical divisions of the brain during the formation of conditioned motor reflexes have been studied in man by V. E. Maiorchik, V. S. Rusinov and G. D. Kuznetsova [3], I. A. Peimer and A. A. Fadeeva [7], T. M. Mokhova [5], H. Gastaut and his co-workers [1, 2] and others, by the method of verbal reinforcement or by preliminary instruction.

During the formation of delayed inhibition, slow waves were found to appear at the time of depression of the motor reflexes [3]. These authors came to the conclusion that these slow waves, including delta waves, were the electroencephalographic reflection of the change of the cortical cells into a state of inhibition.

In recent years researchers have paid increasing attention to the local reactions of the cortical rhythms, which differ from the general reaction—the blocking of the α-rhythm in the occipito-parieto-temporal region. In work by Gastaut, Roger, Dongier, et al. [1, 2], a conditioned reflex block of the rhythm in the motor area of the cortex of one hemisphere (the so-called Rolandic rhythm) was obtained during the formation of conditioned motor reactions, and an increase in the amplitude of the potentials in this area was obtained during the development of central inhibition.

The aim of the present study was to make a further investigation of the changes in the electrical activity of the cerebral cortex during the formation of conditioned motor reflexes in man. In the present communication we examine changes in the electroencephalogram (EEG), generally found in healthy human subjects and in patients with pronounced cerebral disorders.

METHOD

Investigations were carried out on 40 healthy human subjects and on 8 patients with sequelae of slight head injuries, in the phase of recovery and with no focal nor significant general cerebral changes, aged from 18 to 52 years. Conditioned motor reactions were developed by the method of verbal reinforcement (Ivanov-Smolenskii's method) to complex sound stimuli, consisting of three equal sound signals given at regular intervals. For differentiation, complex sound stimuli were used, also consisting of 3 signals: The first two signals were of the same tone as the conditioned positive signals, but the third was of a different tone. The sound signals were produced by means of a type 3G-2A sound generator or a photophonostimulator. During the investigation the subject sat on an armchair in a darkened, screened room.

In the course of formation of the conditioned motor reactions, tracings were made of the EEG and the electromyogram (EMG) from the right forearm. Bipolar EEG recordings were made on an 8-channel Kaiser ink-recording oscillograph or on a 15-channel Alvar ink-recording electroencephalograph. The electrodes for recording the EEG were situated chain fashion on the skull, from the frontal to the occipital regions, at a distance of 4 cm from each other and 2-3 cm from the midline. We were thus able to examine simultaneously the reactions in the EEG in different areas of the cortex. Before the formation of conditioned motor reactions the orientational reaction to sound was extinguished. The electrodes used for recording the EMG were in the form of round disks, 1 cm in diameter, which were glued to the right forearm with collodion. Altogether 62 investigations were made.

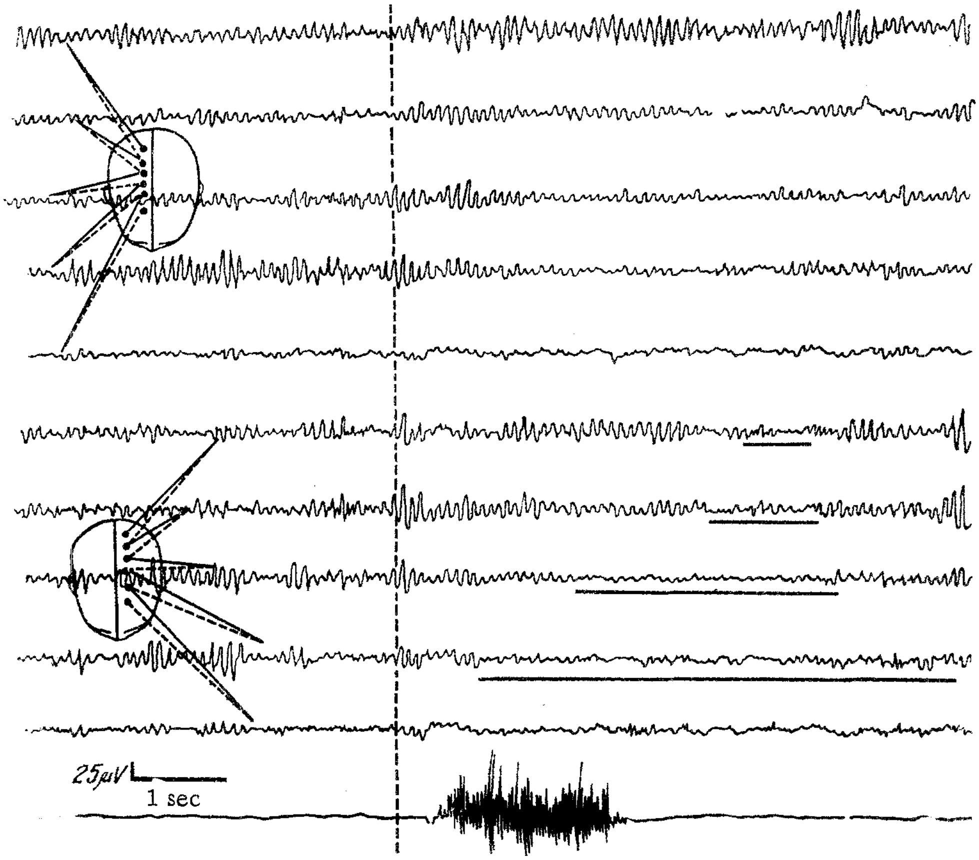

Fig. 1. EEG of the subject P. during an arbitrary movement. Lower line – EMG of the right forearm; the broken vertical line corresponds to the time of giving the instruction "squeeze"; the leads correspond to the illustration.

RESULTS

At the beginning of the investigation the light signal was given several times and the subject was then asked to clench the fingers of the right hand into a fist or to squeeze a rubber balloon. During the light stimulation we observed, like other authors, a general block of the α-rhythm in all areas; if the subject had a well-marked Rolandic rhythm, after the first application of the light an incomplete and transient depression of this rhythm was observed (about 0.2 second); after the repeated application of the light signal the Rolandic rhythm was not depressed but in some cases was even increased in amplitude.

During the first motor reactions two types of changes were observed in the EEG. In one group of subjects there was a general depression of the rhythms in all areas of the cerebral cortex, arising immediately after the word "squeeze." It may be thought that this general depression was caused by the influence of a nonspecific system in the brainstem. This depression of the rhythms subsequently had a tendency either to be concentrated in the motor area as the motor reactions were repeated, or to disappear. In the other group an obvious local reaction was observed, in the form of depression of the α-like rhythm in the motor of the left hemisphere, which began immediately after verbal reinforcement, before the development of the motor reaction (from the EMG).

It is interesting that in some cases the blocking of the rhythm was observed to spread from the motor to the posterior divisions of the brain, and depression of the motor area was still present after a considerable time (Fig. 1).

The reactions in the EEG to sound stimuli were the same in both groups of subjects. The first application of an indifferent sound stimulus is known to evoke general depression, which is extinguished after a few repetitions of the stimulus. When the reaction to each separate sound stimulus was extinguished, the use of complex sound stimuli, consisting of three equal sounds, caused no perceptible reaction in the EEG.

After extinction of the orientational reaction to the sound stimulus, this was used in conjunction with verbal reinforcement—the word "squeeze," given at the time of the 3rd sound signal of the group. After 3-9 combinations a conditioned motor reflex was formed.

In the course of formation of conditioned motor reactions in the first group of subjects, depression of the rhythms in all areas of the cerebral cortex was observed in response to the first combination of the complex stimulus including the word "squeeze." After repetition of the combination, concentration of the depression was observed in the motor area of the left hemisphere. This general depression may reflect a process of generalization of the excitation. In Fig. 2 we give as an example the

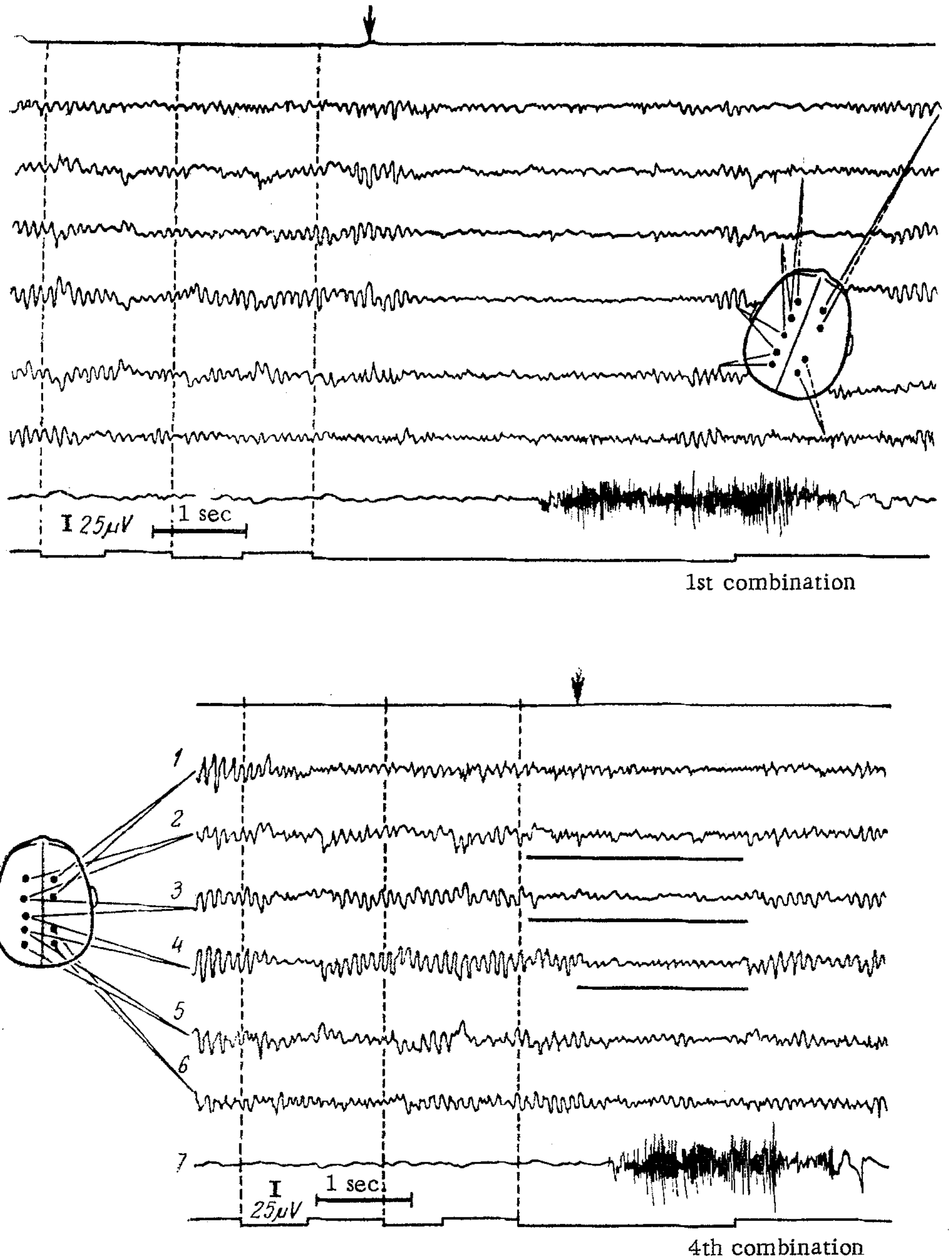

Fig. 2. EEG of the subject Ya. during formation of conditioned motor reflexes. a) 1st combination; b) 4th combination; top line – marker of verbal instruction (arrows). 2nd line from the bottom – EMG of the right forearm; depression of the bottom line – marker of sound stimulus; 3rd sound prolonged; leads corresponding to the diagram.

EEG of the subject Ya. In response to the first combination, depression of the α-rhythm is observed in all the leads after verbal reinforcement with the word "squeeze;" later, in response to the 4th combination, no general depression was recorded. It must be stated, however, that in the parietal motor areas (when leads were taken from a pair of electrodes situated in the motor and parietal areas and from another pair situated in the parietal and posterior parietal areas) the reaction of suppression of the rhythm was observed at the beginning of application of the 3rd conditioned signal of the group; in other areas a change in the action potentials was observed only during movement of the hand (from the EMG), and moreover the movement appeared after a shorter latent period, almost at once after the verbal reinforcement.

On presentation of the conditioned signals to the second group of subjects, only a local depression of the rhythms in the motor areas was observed. There was no generalized depression. During repetition of the conditioned stimulus, local depression was observed at the 3rd sound, before the fingers were clenched into a fist which may be evidence of the formation at that stage of a temporary connection. In some subjects a local reaction of the EEG to the first sound was recorded.

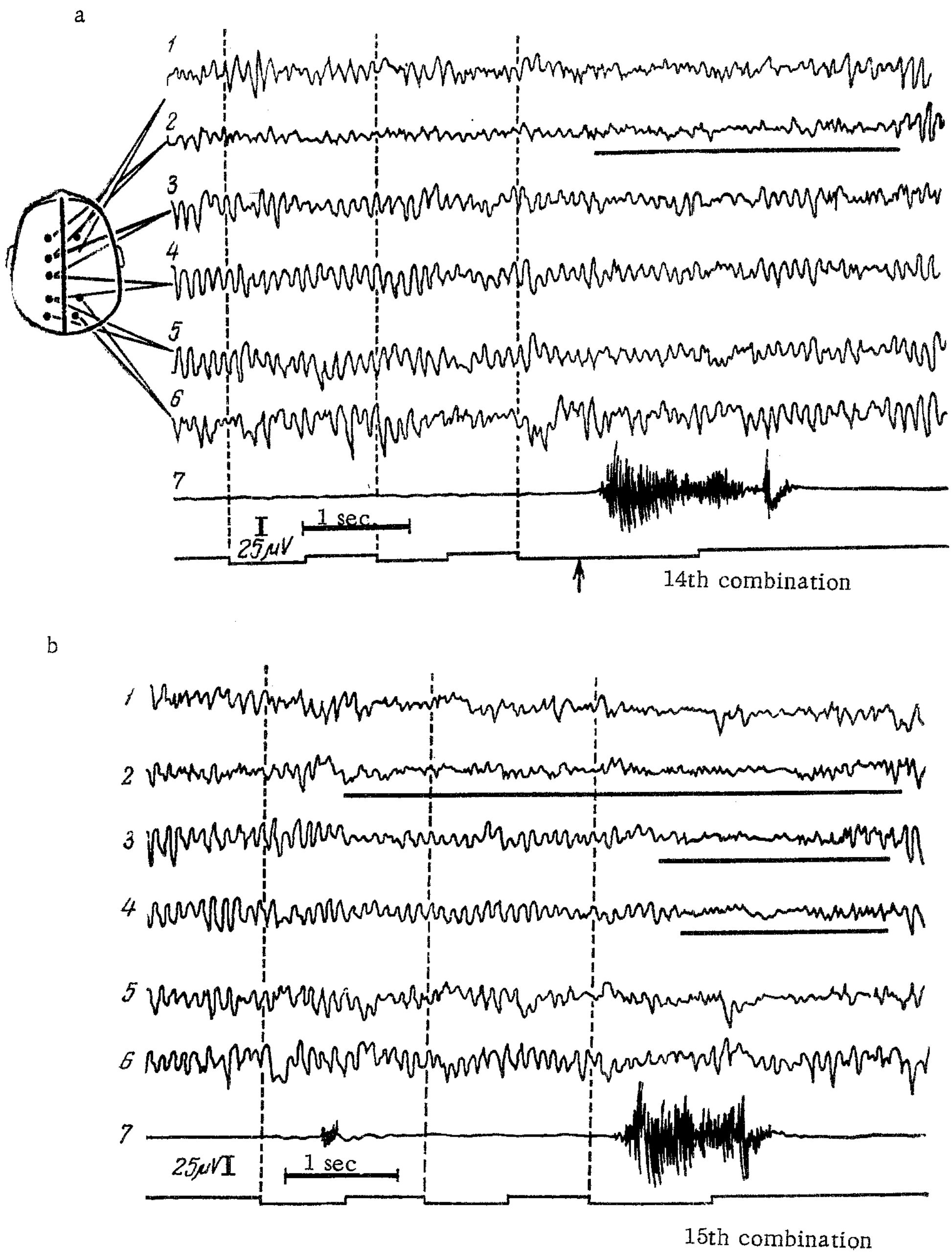

Fig. 3. Changes in the EEG during the formation of conditioned motor reactions in the subject P. a) 14th combination; local depression of the rhythm in the motor area on the left (2) was observed only in response to clenching the right hand; b) after the command, depression of the rhythm was observed at the first sound, lasting to the end of the movement; during the movement it also appeared in other leads; the leads correspond to the diagram; depressions of the bottom line – marker of the sound stimulus.

In cases in which there was prolonged inhibition of the conditioned motor reaction from the second signal system, i.e., the subjects responded by movement only after verbal reinforcement, the command "squeeze the fingers at the 3rd signal" was given during the investigation.

In response to the first application of the combined stimulus after the command, the character of the reaction in the EEG changed. Depression was now observed in response to the giving of the first signal of the group. In some subjects a general blocking of the rhythms in all areas was at first observed, but with the continuing application of conditioned signals, blocking was recorded only in the motor area of the left hemisphere. The blocking began at the first signal of the group, then the rhythm was restored, but the depression arose again at the beginning of the 3rd sound signal, before clenching of the fingers. In other subjects local changes, in the form of depression of the motor area only (Fig. 3), were observed in response to the first conditioned stimuli after the command. Depression began at the first signal and continued until the end of clenching the fingers into a fist. In response to subsequent conditioned signals, no depression of the rhythm was observed at the first signal of the group; it occurred only in response to the 3rd signal of the group.

After 15-20 combinations of the conditioned positive signal with verbal reinforcement the 3rd sound signal was omitted from the group. Under these circumstances, in some cases, a motor reaction to time was observed, expressed in the EMG in the form of waves of potentials of low amplitude. When the subjects were questioned after the investigation, they replied that they clenched their fingers "unarbitrarily." The EEG at the same time showed either depression of the α-rhythm in all areas or a local reaction in the sensomotor area.

In some observations the reaction to time was expressed in the EEG as a local, and not a general depression of the rhythms (in the sensomotor area), later spreading to the parietal and occipital regions. After depression, the α-rhythm was restored earlier in the occipital region, and then in the parietal region. Depression lasted longest of all in the motor areas, and its duration was shortest in the occipital area. On a multichannel recording of the EEG, depression was expressed in the form of a "funnel." This change was observed in response to the first and second times that the omission was practiced, and also at the beginning of formation of differentiation to the combined stimulus, or during transformation of the positive stimulus into an inhibitory stimulus, and vice versa. This phenomenon, not previously described in the electrophysiological literature, apparently reflects a process of irradiation and subsequent concentration in the cerebral cortex.

The following conclusions may be drawn from these investigations. During the formation of motor conditioned reflexes in man (by the verbal-motor method) in response to compound sound stimuli, consisting of three equal sound signals, general changes are observed in the action potentials of the EEG, in the form of depression of the α-rhythm, which has a tendency to become concentrated in the sensomotor area after the application of the 3rd signal of the group. During the first occasions on which the 3rd sound was omitted, at the moment after the 2nd sound corresponding to the time of the 3rd sound, spreading of the depression of the α-rhythm from the cortical end of the motor analyzer to the occipital region was observed; recovery of the rhythm took place in the opposite direction.

SUMMARY

The author studied the EEG changes in man during the formation of conditioned motor reflexes to complex sound stimuli.

The data obtained permit 3 types of reactions to be distinguished: 1) A generalized depression of the alpha-rhythm; 2) a local depression of the alpha-rhythm in the motor area of the "active" hemisphere, and 3) a depression in the form of a "funnel."

In the latter, the depression started from the motor area, and subsequently spread in the occipital direction. The recovery of the alpha-rhythm proceeded in the reverse direction. Depression in the motor area was retained the longest.

In the author's opinion, these changes in the electroencephalogram reflect an irradiating process in the cerebral cortex with its subsequent concentration.

LITERATURE CITED

[1] H. Gastaut, A. Joos, F. Morel, et al., Zhur. Vysshei Nerv. Deyatel. 7, 1, 25 (1957).

[2] H. Gastaut, A. Roger, S. Dongier, et al., Zhur. Vysshei Nerv. Deyatel. 7, 1, 185 (1957).

[3] V. E. Maiorchik, V. S. Rusinov, and G. D. Kuznetsova, The Physiological Basis of Neurosurgical Operations (Moscow, 1954), p. 48 [In Russian].

[4] V. E. Maiorchik and B. G. Spirin, Voprosy Neirokhirurg 3, 3 (1951).

[5] T. M. Mokhova, Zhur. Vysshei Nerv. Deyatel. 6, 2, 319 (1956).

[6] R. A. Pavlygina and V. S. Rusinov, cited by V. S. Rusinov, Paper at the Fourth International Electroencephalographic Congress in Brussels, 1957 (Moscow, 1957) [In Russian].

[7] I. A. Peimer and A. A. Fadeeva, Fiziol. Zhur. SSSR 42, 3, 319 (1956).

[8] P. I. Shpil'berg, Byull. Eksptl. Biol. i Med. 24, 6, 271 (1947).

[9] G. Durup and A. Fessard, cited by V. S. Rusinov, Zhur. Vysshei Nerv. Deyatel. 7, 6, 855 (1957).

[10] H. Jasper and C. Shagass, J. Exper. Psychol., 28, 373 (1941).

[11] A. L. Loomis, E. N. Hervey, and G. Hobart, J. Exper. Psych. 19, 249 (1936).