# HUMAN EEG DURING FORMATION OF CONDITIONED REFLEXES

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Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 50, No. 9,
pp. 11-16, September, 1960
Original article submitted June 17, 1959

Until recent times, in studies of the processes of higher nervous activity, observations of only the terminal effects (motor, secretory, etc.) of invoked reflexes were possible. The development of electroencephalography has permitted study of these processes by the direct display of the bioelectric activity of nerve cells of the cerebral hemispheres.

Simultaneous registration of potentials in various cortical areas discloses varied electrical changes which are a manifestation of the mosaic of cortical activity.

Numerous investigations conducted on animals [1, 3-11, 13-21] have made possible the elaboration and confirmation of the basic tenets of the doctrine of I.P. Pavlov concerning conditioned reflexes, and have disclosed some new features of the processes involved in higher nervous activity.

Of particular significance is the explanation of the mechanism of dynamic electroencephalographic changes related to the various developmental stages of conditioned reflexes. These changes were observed by M. I. Livanov [9, 10], who noted the progressive reduction in the extent of cortex responding to the conditioned stimulus.

Changes in the human electroencephalogram during the formation of motor conditioned reflexes were reported by Gastaut and his collaborators [17, 18, and 19], who observed the gradual restriction of the zone of conditioned-reflexive depression to the region of the involved analyzer.

In order to investigate electroencephalographic changes during prolonged reinforcement of conditioned reflexes, we conducted observations on more than 60 healthy people.

## METHOD

A four-channel inkwriting electroencephalograph was used for recording. Potentials were led off from the surface of the head by silver electrodes mounted in a glass cap secured by rubber bands. During the development of the defensive conditioned reflex involving electrocutaneous reinforcement, the subject's hand rested on a "mushroom" whose contacts were connected to the induction coil. During the development of conditioned reflexes involving reinforcement by passive movement, the right hand was placed on a movable plate whose end (where the wrist lay) could be raised by the experimenter.

In addition, a motor conditioned reflex involving reinforcement by a verbal stimulus ("press") was developed according to the method of A. G. Ivanov-Smolenskii [2, 12].

The electrical activity of the brain was simultaneously recorded, as well as a myogram of the extensor or flexor digits of the hand.

## RESULTS

Prior to the development of the conditioned reflex, observations were made of the dynamic extinction of the orientative electroencephalographic reaction in response to the application of the stimulus which was subsequently used in conditioning. During this period there occurred a gradual organization, involving blocking of the basic rhythm and subsequent weakening of this reaction.

Thus, with the initial use of auditory stimulation, a generalized depression set in not only in the region of the auditory analyzer, but also in the motor and visual analyzers. However, after 10-20 trials with this stimulus alone, this depression was completely absent.

A gradual weakening of the blocking reaction was also observed with a visual stimulus, but this occurred after a considerably greater number of trials (25-30) with the visual stimulus, and a completely extinguished reaction was not noted.

In the first series of experiments, a conditioned reflex to a metronome was developed by combining the sound (120 beats/min) with passive elevation and lowering of the right hand. This movement produced a generalized reaction of depression in all leads. With repetition, however, this depression persisted only in the Rolandic region of the left hemisphere.

With formation of the conditioned reflex (4-8 trials) the auditory stimulus produced a conditoned-reflexive generalized reaction of depression of basic rhythms in both hemispheres, at first in the left and then in the right, with engagement of the auditory analyzer (Fig. 1a). After subsequent trials (20-30) onset of the metronome and conditioned-reflexive elevation of the

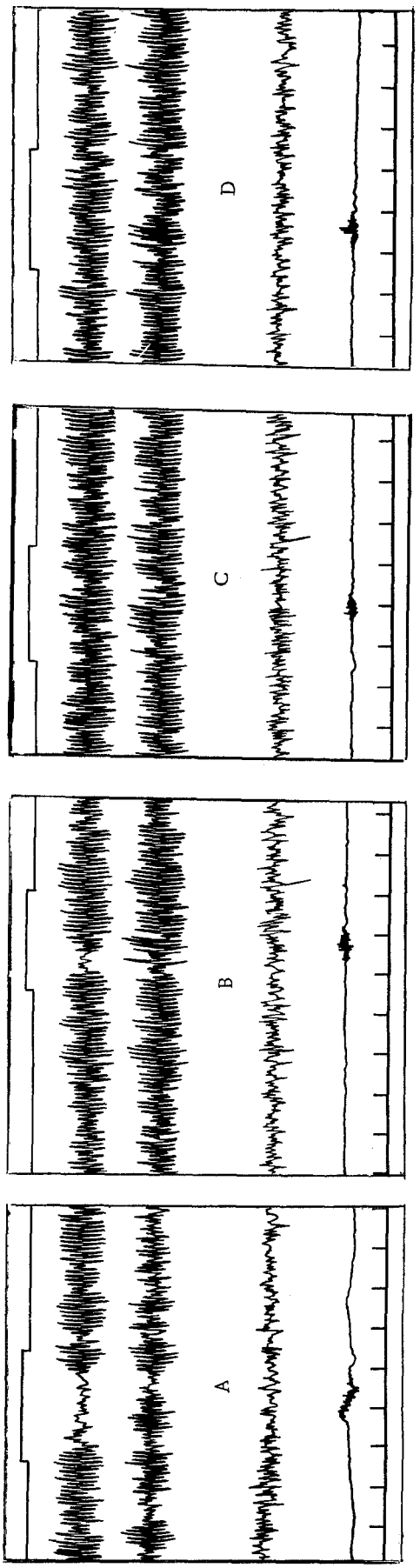


Fig. 1. Changes in the EEG during a conditioned reflex involving the sound of a metronome combined with reinforcement by passive elevation and lowering of the hand (subject P., age 20). A) Generalized depression, spreading successively from the left Rolandic region to the right Rolandic and temporal regions (10th trial); B) organized depression chiefly in the left Rolandic region, preceding the conditioned-reflexive movement (28th trial); C) absence of visible depression after prolonged practice (79th trial); D) same as (C) (80th trial). Channels (reading down): onset and termination of auditory conditioned stimulus; EEG with left Rolandic lead; EEG with right Rolandic lead; EEG with temporal lead; general myogram of extensor digits of right hand; time in seconds.

right hand produced blocking of the basic rhythm only in the left Rolandic region (Fig. 1b). Some hypersynchronization of the basic rhythm might be observed in the right Rolandic region at this time, apparently indicating the indirect relationship between processes in symmetrical parts of the motor analyzer. With further practice and strengthening of the conditioned reflex, electroencephalographic changes in response to the conditioned stimulus progressively diminished even in the left Rolandic region. Finally, after 60-80 trials, the conditioned stimulus no longer produced depression of the basic rhythm (Fig. 1c, d).

In the next series of experiments, motor reflexes were produced by verbal reinforcement according to the method of A. G. Ivanov-Smolenskii. A bell sound of moderate loudness was combined with the verbal reinforcement "press", with the latter occurring 1.5 seconds after the beginning of the conditioned stimulus. With development of the conditioned reflex (2-5 trials), there occurred a generalized basic rhythm depression which corresponded to the movement of the right hand as the rubber bulb was pressed (Fig. 2a).

Strengthening of this conditioned reflex (15-20th trial of bell with verbal reinforcement "correct") led to a focusing of the depression in the left Rolandic region only, at the moment of conditioned-reflexive movement of the right hand (Fig. 2b).

Subsequently, by the 40-50th trial, blocking of electrical activity could no longer be seen even in the left Rolandic region, regardless of the fact that the auditory signal continued to produce conditioned-reflexive movement of the hand (Fig. 2c).

In the third series of experiments a motor-defensive reflex was produced. The sound of the metronome (120 beats/min) was used as the conditioned stimulus, and electric shock to the right wrist as the unconditioned stimulus.

The conditioned stimulus preceded the unconditioned stimulus by 2 sec, and also lasted during the following 2 sec of the latter. With presentation of the electrocutaneous stimulus, blocking was noted in all leads, particularly in the contralateral Rolandic region. The conditioned reflex was developed by the 5-15th trial. The sound of the metronome produced a generalized depression which spread from the left Rolandic region to the right Rolandic and temporal regions.

With consolidation of the motor conditioned reflex (20-25th trial) this depression evoked by the metronome was maintained only in the left Rolandic region. Full extinction, however, of the electroencephalographic reaction was not observed in this series of experiments. A similar electroencephalographic reaction occurred with the development of a conditioned reflex involving the flickering of an electric light bulb (2 times per sec) combined with passive elevation and lowering of the right hand, with the latter loosely resting on a movable

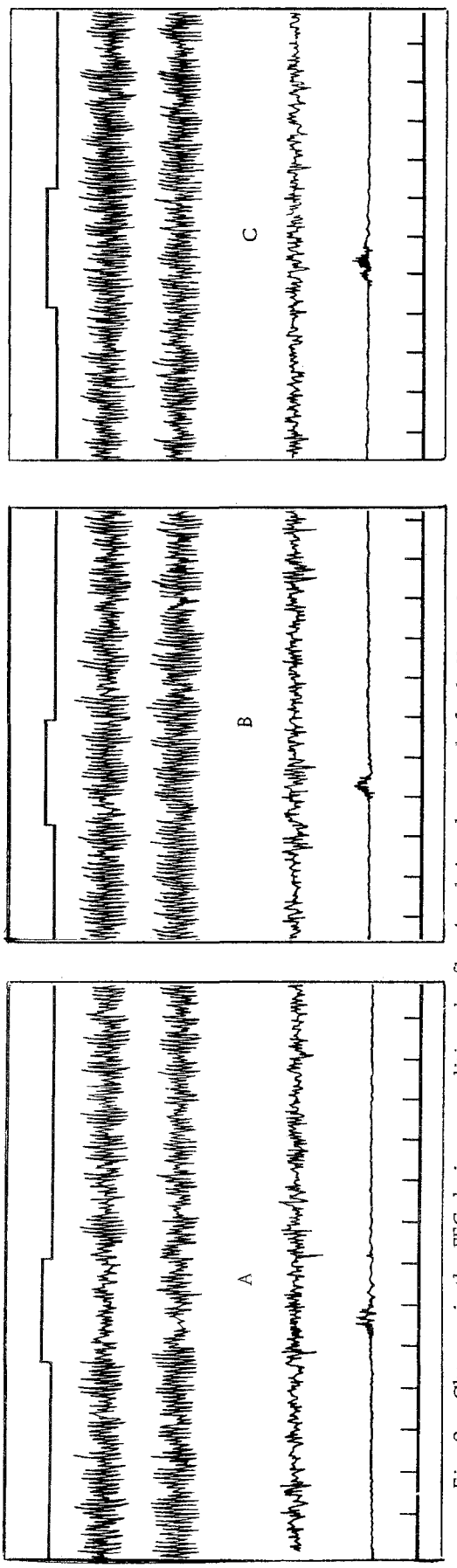


Fig. 2. Changes in the EEG during a conditioned reflex involving the sound of a bell combined with verbal reinforcement (subject P., age 20). A) Generalized basic rhythm depression corresponding to movement produced by right hand pressing rubber bulb (6th trial); B) organized depression in left Rolandic region, preceding conditioned-reflexive movement (18th trial); C) absence of visible depression after prolonged practice (49th trial). Channels (reading down): onset and termination of auditory conditioned stimulus; EEG with left Rolandic lead; EEG with right Rolandic lead; EEG with temporal lead; myogram of flexure of right hand digit; time in seconds.

plate. With development of this reflex, conditioned-reflexive blocking was first noted in the Rolandic region involving both hands, and also in the occipital region (after 5-15 trials).

With strengthening of the reflex (30-40 trials) the reaction was maintained only in the Rolandic region.

Thus, with the development of motor conditioned reflexes in humans, one can observe, at first, a generalized depression of the alpha-rhythm in all leads which is gradually restricted to the region of the contralateral motor analyzer.

Further strengthening of the conditioned reflex leads to the gradual abolition of this conditioned-reflexive electroencephalographic reaction. It was shown that it is possible to achieve a situation in which some conditioned stimuli, e.g., sound, do not produce observable changes in the basic electrical activity of the brain, although they continue to evoke conditioned-reflexive movements.

The disappearance of conditioned-reflexive depression of the alpha-rhythm with prolonged practice occurs most rapidly with reflexes involving verbal reinforcement, and least with motor-defensive reflexes.

## SUMMARY

The EEG changes, with prolonged repetition of conditioned reflexes (elaborated according to the method of defensive and speech-motor conditioned reflexes), were studied in 60 healthy individuals.

The reaction of the alpha-rhythm depression observed at the beginning in all of the leads, gradually becomes limited to the area of the motor analyzer, on the side contralateral to the reinforcing movement.

Further strengthening and repetition of a conditioned reflex results in a gradual leveling out of the conditioned-reflex electroencephalographic reaction. Such condition may be attained when it becomes very difficult, or even impossible, to detect any changes in the main electric activity of the brain in response to some stimuli, for instance, acoustic ones, although these are still capable of provoking conditioned reflex motor reaction.

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