PHYSIOLOGY

COMPARISON OF THE ELECTRICAL RESPONSE OF THE RETICULAR FORMATION, THALAMUS, AND CORTEX TO A SERIES OF IDENTICAL STIMULI FROM AN INDUCTION COIL

M. M. Bantsekina

From the Laboratory of the Physiology of the Central Nervous System (Head – Active Member of the AMN SSSR P. K. Anokhin) N. N. Burdenko Institute of Neurosurgery (Director – Active Member of the AMN SSSR V. G. Egorov) AMN SSSR, Moscow

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In recent years, many workers have shown that afferent impulses may reach the cortex by two routes, passing along either the classical lemniscal or along the nonspecific pathways. The nonspecific afferent system of the brain stem has its own nuclei and its own distinct tracts and comprises the reticular formation, localized in the brainstem (diencephalon, mesencephalon) and in some of the thalamic nuclei. This system has a widespread nonspecific projection onto the cortex.

It has been suggested [2, 7, 9] that the reticular formation does not carry out any specific function, but establishes an appropriate level of exitability which enables processes to take place which are induced by afferent impulses passing along the specific pathways.

It is also known [7,10] that all sensory impulses pass along many collaterals in the region of the reticular formation of the brainstem where they interact extensively by multisynaptic connections and lose their original sensory specificity.

Direct stimulation of the reticular formation of the brainstem induces the so-called "waking" reaction on the electroencephalogram (EEG), and the animal passes from a state of sleep to one of wakefulness. When this region is inactivated, either functionally or anatomically, the normal animal goes into coma and fails to react to any stimulus.

Work by foreign authors on the pathways for nociceptive stimuli has consisted of direct stimulation or of elimination of different parts of the brain stem [4,5,6,10].

V. G. Agafonov [1] showed that the flow of pain impulses (induced by placing the rabbit's foot in hot water) could be blocked by an injection of aminasin. It was natural to suppose that pain is developed in the higher nervous centers only after some more specific "nucleus" has been established at a lower level in the brainstem. Probably, such a physiological integration making the whole reaction specific takes place at the level of the reticular formation and in the hypothalamus [2].

The present investigation reports the development of electrical activity in the reticular formation of the brainstem, thalamus, and cortex in response to painful stimulation.

METHOD

The experiments were carried out on 40 unanesthetized rabbits weighing about 2 kg.

Three to four days before the experiment, the skull was trepined under local anesthetic, and electrodes were inserted in the following subcortical structures of the left side: 1) in the reticular formation of the brainstem (medial portion), 2) in the lemniscal system of the brainstem (lateral portion), 3) in the medial thalamic nucleus.

The placement of the electrodes in these structures was made using the coordinate system of Gangloff and Monnier [3].

The potentials from the cortex were led off from the sensory motor and temporal regions of the cortex, the electrodes being placed on the internal surface of the calvarium.

The bipolar buried electrodes were made from nichrome wire 100 μ in diameter, and the cortical electrodes from 500 μ diameter steel wire.

All the electrodes were fixed to the skull with phosphate cement. During the experiment, the animal was held in a special support ("hammock").

The skin of the hindfoot was stimulated with a series of identical stimuli from an induction coil.

Potentials from the brain were taken to an amplifier and recorded on a four-channel ink writer which also recorded the stimuli and time intervals.

At the start of the experiment, the strength of the current required to effect an alteration of the electrical activity in all the structures from which recordings were taken was determined. As the experiment proceeded, the stimulus strength was changed as circumstances dictated.

To avoid a conditioned reflex being developed and associated with the time of stimulation, the stimulus was applied at different time intervals from 30 seconds to 20 minutes.

After the experiment, a histological check on the position of the electrodes was made.

RESULTS

At the beginning of the experiment, the EEG of the brain structures studied gave a picture which was typical of the orienting and searching reaction: there was a desynchronization in the sensory motor cortex, and low amplitude synchronization in the reticular formation of the brainstem and thalamus.

After a certain time interval, during which the animal lay quietly in the support, the electrical potential changed and gradually went over to those characteristic of the resting condition. In the reticular formation of the brainstem and in the medial thalamic nucleus, the EEG "resting" rhythm consists of low amplitude waves at a frequency of 5-8 per second alternating with periods of various duration at different amplitudes. In the sensory motor region of the cortex, the "resting" rhythm of the EEG consists of waves at a frequency of 2-3 per second of varyng amplitude (usually high), and these appear as though distorted by rapid oscillations, at 25-30 per second and by periodically occurring bursts of "spindles". In the temporal cortical region, the "resting" rhythm consists of high amplitude oscillations, at a frequency of 5-6 per second.

For each animal, the period of "resting" occurred after a different interval of time; only after the appearance of the "resting" background of the EEG did we apply the series of identical induction shocks.

The reaction to the equal pain unconditioned stimulus consists of definitive and characteristic changes in the EEG: first the irregular rhythm of electrical activity of the reticular formation changes over to a very regular rhythm, at a frequency of 4-6 per second, i.e., it becomes synchronized, and secondly, in the sensory motor cortex, the initial "resting" current changes over to a high frequency, low amplitude oscillation, i.e., it becomes desynchronized; thirdly, in the temporal region of the cortex, there is a change toward a regular synchronized rhythm with potential variations at a frequency of 4-6 per second (Fig. 1, a).

It must be emphasized that in the structures studied, the alteration in the EEG develops in response to the application of identical and very short-lasting stimuli (lasting only a fraction of a second), while the change

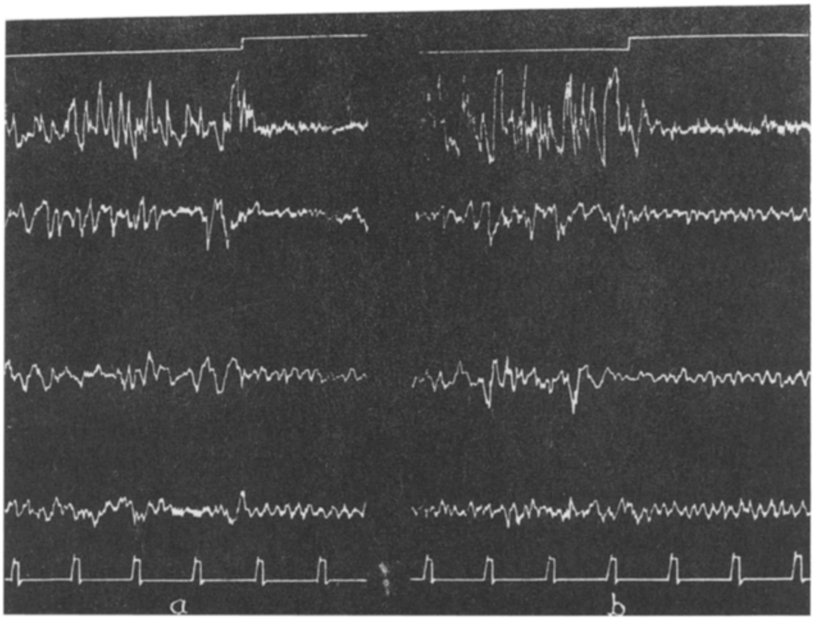

Fig. 1. Changes in the rabbit EEG in response to a series of identical electrical cutaneous stimuli. Curves, from above downwards: stimulus marker; sensory motor region of cortex; temporal region of cortex; medial division of the thalamus; reticular formation of the brainstem (superior corpora quadrigemina); time marker (1 second). a) Desynchronization in the sensory motor region of the cortex and steady rhythm in the reticular formation of the brain stem, thalamus, and temporal cortex, in response to a series of equal electrical cutaneous stimuli corresponding to 13 cm on the scale of the induction coil (5th stimulation); b) phenomenon of "bahnung" with repetitive application of the stimulus (strength of current 22 cm on induction coil) (reduced voltage produces an identical change in EEG).

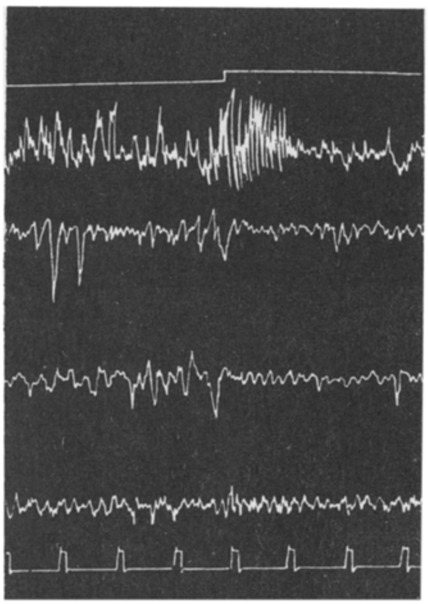

Fig. 2. Changes in the EEG of the reticular formation of the brainstem and thalamus, occur earlier than those in the sensory motor cortex, in response to application of the first stimulus. Traces as in Fig. 1.

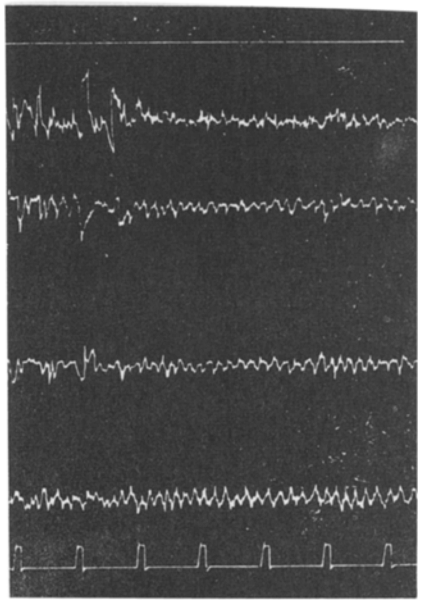

Fig. 3. Conditioned reflex changes in the electrical activity to any kind of sound (at end of experiment). Traces as in Fig. 1.

produced lasts form many seconds. The regular electrical oscillations in the temporal region are synchronous with those in the subcortical structures (reticular formation of the brainstem and medial thalamic nucleus).

Subsequent application of the same stimulus brings about the phenomenon of "bahnung", i.e., a smaller voltage will now produce an identical change in the electrical activity (Fig. 1,a,b).

It is particularly interesting to observe that the use of a weak electrical stimulus of a definite strength, brings about a dissociation in the time of the appearance of the EEG in the subcortical structures, as compared with the cortex; first of all, the electrical activity changes in the reticular formation and in the medial thalamic nucleus, but only after a period of 0.2-0.4 seconds does the same change occur in the sensory motor cortex (Fig.2), the EEG reaction of the subcortical structures occurs before that in the cortex.

A detailed analysis of this dissociation, shows that a gradual increases in the strength of the stimulus may have the effect that a single shock causes a typical EEG reaction which is shorter than usual in the brainstem and thalamus, while in the sensory motor cortical area, the same stimulation produces no visible changes in electrical activity. With subsequent repititive sitimulation at the same intensity, or with a stronger single stimulus (and the same recording rate), it is not possible to reveal any difference in the time of the appearance of the reaction at the different levels; the stronger the current and the higher the stimulus frequency, the more definite and prolonged is the complex reaction.

Thus, a single stimulation applied to the skin produces a fairly constant EEG reaction, which takes the form of a change in the rhythm of the reticular formation and of the medial thalamus, and which slightly precedes the desynchronization in the region of the sensory motor cortex; the reaction continues for as long as several seconds after the action of the single stimulus. By the end of the experiment, this EEG reaction has assumed the nature of a conditioned reflex, and the characteristic change in the rhythms of the reticular formation of the brainstem and the thalamus, as well as in the sensory motor and temporal cortical regions, develops in response to the slightest sound (Fig. 3).

Bearing in mind that stimulating the skin with a single shock produces, first, a change in the electrical activity of the reticular formation of the brainstem followed immediately afterwards by a change in the sensory motor cortex, it must be supposed that the complete pain reaction develops first at the reticular level, and that the excitation does not spread to the highest levels of the brain until later, as is revealed by the desynchronization of the potentials in the sensory motor cortex.

However, on account of the more rapid spread of the excitation along the lemniscal system [8], it is probable that the conditioned reflex pain reaction is due to impulses flowing back from the cortex along the corticofugal pathways to the reticular formation.

SUMMARY

Single cutaneous electrical stimuli evoke the following changes in cerebral electrical activity: synchronization in the reticular formation, medial thalamus, and temporal cortex, with desynchronization in the sensory motor cortex. Low voltage stimuli produce changes in the EEG of the reticular formation which appear earlier than do those of the sensory motor cortex. In the author's opinion, pain is first signaled at the level of the brainstem, and later the excitation moves up to the higher levels.

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