ELECTROMYOGRAPHIC EFFECTS OF STIMULATION OF THE MOTOR POINTS OF THE CEREBRAL CORTEX IN DOGS AFTER HEMISECTION OF THE SPINAL CORD

S. N. Ivanova

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In earlier investigations [7, 8], the author recorded mechanographically the motor effects in the affected limb produced by stimulation of the motor points of the cerebral cortex in dogs after lateral hemisection of the spinal cord. As a result of these experiments, and in contrast to findings obtained by earlier workers [10-13], it was found that in chronic experimental conditions movements of the limb could be produced on the side of hemisection of the spinal cord in response to electrical stimulation of the corresponding points of the motor cortex.

The object of the present investigation was to study the electromyograph (EMG) of the antagonist muscles of the forelimb on the side of lateral hemisection of the spinal cord in response to stimulation of the motor cortex.

EXPERIMENTAL METHOD

Experiments were carried out in chronic conditions on unanesthetized dogs. The EMG of antagonist pairs of muscles – the flexor and extensor of the forelimb – was studied during stimulation of the motor points of the cortex of the corresponding hemispheres. In order to stimulate the cortex the electrodes were implanted in burr-holes in the skull in the region of the cortical representation of the forelimb. In every case lateral hemisection of the spinal cord was carried out at the level of C2-3 on the left or right side. The EMG of the antagonist muscles of the affected limb, evoked in response to stimulation of the motor cortex, was investigated before and after hemisection of the spinal cord.

The experimental conditions, the method of stimulation of the cortex, and also the method of recording the mechanogram of flexion of the forelimb at the elbow joint were described in previous papers [7, 8]. The EMG of the antagonist pair of muscles was recorded by means of implanted electrodes by the author's technique [9]. Later in the account, the forelimb corresponding to the side of hemisection will be called the affected limb.

EXPERIMENTAL RESULTS

Before hemisection of the spinal cord, in response to stimulation of the motor points of the dogs' cortex a definite pattern of electrical activity of the flexor and extensor muscles was observed. Stimulation of the cortex at threshold strength evoked a minimal electromyographic response of the flexor, manifested externally as a spasm of the limb. An increase in the strength of the stimulus evoked both an increase in the electrical activity of the flexor and involvement of the extensor in the response reaction. The evoked flexion of the limb through approximately 90° took place as a result of marked activity of both flexor and extensor. With an increase in the strength of the stimulus the frequency of the muscle potentials and their amplitude increased. The electromyographic response in the intact dogs is shown in Figs. 1a and 2a. As is clear from Fig. 1a flexion of the limb at the elbow by 90° (the 3rd line from the top) was accompanied by the development of electrical activity simultaneously in the flexor (1st line from the top) and extensor (2nd line from the top). The frequency of the muscle potentials on the EMG evoked by cortical stimulation was 160-180 cps (only the peak of the potentials directed upward were counted for a period of 1 sec from the beginning of cortical stimulation).

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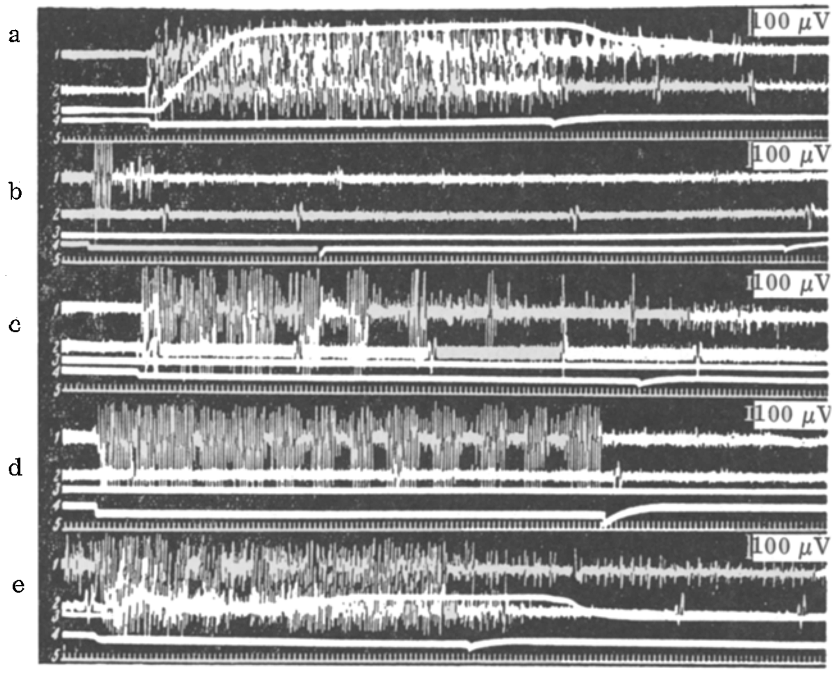

Fig. 1. EMG of muscles of the affected forelimb of dog No. 7 before hemisection of the spinal cord (a) and 3 (b), 15 (c), and 24 (d) days and 2 months (e) after lateral hemisection. 1) EMG of flexor; 2) EMG of extensor; 3) Mechanogram of flexion of the affected limb (deviation of the line upward); 4) marker of electrical stimulation of the cortex; 5) time marker 20 msec.

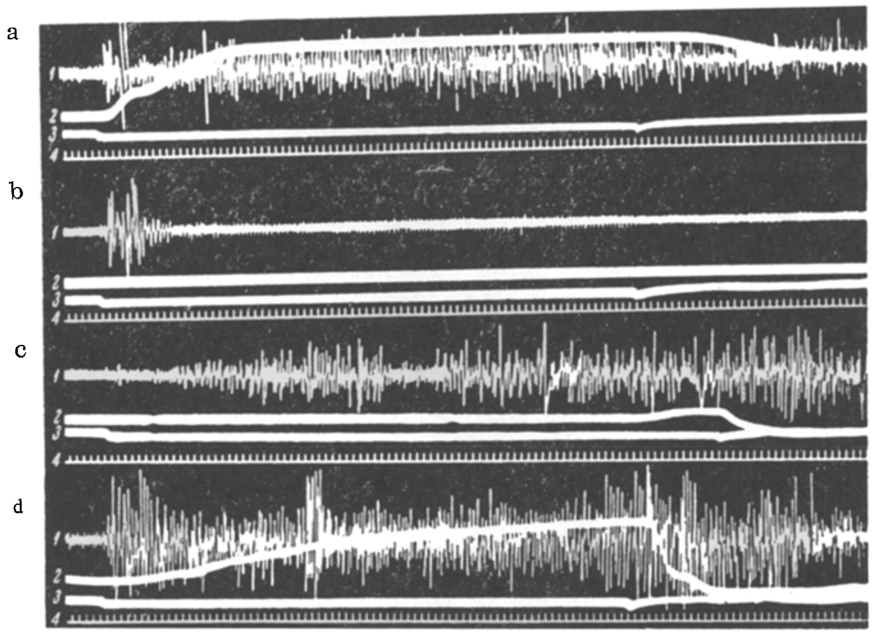

Fig. 2. EMG of the flexor of the affected forelimb of dog No. 4 before (a) and 5 (b), 14 (c) and 19 (d) days after lateral hemisection of the spinal cord. 1) EMG of flexor; 2) mechanogram of flexion of the affected limb (upward deflection of the line); 3) marker of electrical stimulation of the cortex; 4) time marker 20 msec.

The latent period of appearance of the EMG in response to cortical stimulation in these experimental conditions was approximately 20-30 msec. The mechanographic response – flexion of the limb at the elbow – developed somewhat later than the EMG, after a latent period of about 40-60 msec.

After determination of the EMG of the antagonist pair of forelimb muscles in the intact dogs in response to stimulation of the corresponding points of the motor cortex, lateral hemisection of the spinal cord was carried out.

Hemisection of the spinal cord introduced considerable changes into the bioelectrical activity of the antagonist muscles. Analysis of the EMG tracings obtained during the experiments showed that these changes took place in a series of stages.

The first stage was characterized by the absence of both mechanoreceptors and electromyographic responses from the affected limb to stimulation of the corresponding motor points of the contralateral cerebral cortex. This lasted approximately for the first 2-3 days after the operation. Later slight activity appeared in the flexor; the EMG of the extensor and the motor reaction of the affected limb were still absent. Sometimes even a considerable increase in the strength of the stimulus (compared with the strength which, before hemisection, evoked flexion of the limb at the elbow by 90°) evoked activity in the flexor only at the beginning of the stimulus (Figs. 1b and 2b). The latent period of the evoked EMG in some dogs was increased to 40-60 msec. Such observations were usually made until one week after hemisection of the spinal cord.

The next stage continued approximately 2-3 weeks after the operation. The aggregated EMG at this time was considerably changed by comparison with that in the preceding stage (Fig. 1c and d). The EMG of the flexor was characterized by infrequent potentials of high amplitude, resembling the biopotentials during tremor. Whereas before hemisection the highest amplitude of the EMG averaged 150 μV, in the present period it was almost double, while the frequency fell from 160-180 to 80-100 cps (Figs. 1c, d and 2c, d). By this time the latent period of the EMG had returned to its original length and the bioelectrical activity of the extensor had increased.

However, even when the EMG of the flexor was in this form, the motor response of the affected limb was still absent. Not until about 3-4 weeks after hemisection of the spinal cord (the 3rd stage) did stimulation of the contralateral cortex evoke electromyographic activity in the affected limb of both the flexor and the extensor, and the EMG was close to its original state as regards the amplitude and frequency of the oscillations. It was at this period also that the first evoked flexions of the affected limb appeared [7, 8].

In the experiment described, a marked feature was the difference in the time of recovery of the evoked EMG responses and the flexions of the affected limbs. Whereas an electromyographic effect was observed during the first week after hemisection, flexion of the affected limb could not be evoked until 3-4 weeks after the operation (see Figs. 1 and 2).

As compensation of the disturbed functions of standing and walking developed, the EMG of the muscles of the affected limb showed a gradual return to its preoperative parameters (Fig. 1e). Long observations on the experimental animals showed that whereas the latent periods of the electromyographic responses returned to its initial level during restoration of the disturbed functions, the latent period of evoked flexion at the elbow (the mechanogram) remained much longer than normal [7, 8]. The experimental results showed that division of the principal descending tracts by lateral hemisection of the spinal cord at the level of C2-3 does not prevent the conduction of impulses from the contralateral cortex to the motor neurons of the spinal cord responsible for the activity of the muscles of the affected limb. This conduction of impulses may take place either as a result of activation of the direct pyramidal tracts of the contralateral hemisphere, the axons of which cross over to the opposite side at the level of each segment of the spinal cord, or on account of the crossed pathways of the homolateral hemisphere, or by both methods at the same time.

This hypothesis is perfectly justified because removal of the homolateral cerebral cortex (in relation to the hemisection) leads to a deeper and more prolonged decompensation of the motor functions than removal of the cortex of the contralateral hemisphere [6]. The absence of electromyographic responses from the affected limb, noted during the first days after hemisection, may be explained not only by interruption of the principal conducting tracts, but also by the temporary depression of the secondary or reserve tracts. The subsequent changes in the bioelectrical activity of the muscles, in the form of an increase in the amplitude and a decrease in the frequency of the potentials, evidently reflect a higher functional state of the central nervous structures taking part in the restoration of the disturbed function.

According to reports in the literature, synchronization of the rhythm on the EMG takes place when work is carried out with great muscular effort, associated with the speed of the movements performed, the size of the load, fatigue, and so on. The increased amplitude and the appearance of regular muscle action potentials demonstrate the involvement of numerous neuromotor units in the work and increased synchronization of their activity [3-5].

The synchronized character of the EMG tracings in the present experiment may be regarded as a reflection of the increased activity of the neural elements appearing at a certain stage of compensation of function. This is also shown by the fact that synchronized activity of the motor units was observed in the period preceding the active use of the affected limb for static and locomotor acts.

It is concluded that the EMG in this case reflects the state of the central nervous system at the stage of recovery of disturbed functions which, in the words of É. A. Astratyan, is the phase of exaltation [1,2].

In the present investigation, therefore, the study of the bioelectrical activity of the muscles of the affected limb revealed the electromyographic manifestations of the principal stages of recovery of the motor functions after lateral hemisection of the spinal cord.

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