EFFECTS OF STIMULATION OF CORTICAL MOTOR POINTS IN DOGS AFTER HEMISECTION OF THE SPINAL CORD

S. N. Ivanova

Physiological Laboratory, USSR Academy of Sciences
(Presented by Active Member AMN SSSR N. I. Grashchenkov)
Translated from Byulleten Éksperimental'noi Biologii i Meditsiny, Vol. 56, No. 11, pp. 64-67, November, 1963
Original article submitted July 27, 1962

Lateral hemisection of the spinal cord in cats, dogs, and monkeys causes extensive and profound disturbances of function, notably of standing and walking. Investigations of the late sequelae of this type of spinal cord injury showed that the disturbed locomotor and static functions are gradually and completely compensated [1, 5, 7-14].

Various authors [10-12, 14] have attempted to elicit limb movements on the side of the hemisection by electrical stimulation of the motor area of the cortex of the opposite hemisphere. Only Mott and Schaefer, in their experiments on monkeys, were able to observe weak movements of the previously affected limb, and all other investigators have failed to elicit limb movements on the side of the hemisection. Hence, on the one hand, after hemisection of the spinal cord the static and locomotor functions are practically fully restored, while on the other hand, electrical stimulation of the cortical motor points in the same animals does not cause movements of the affected limb.

This contradictory situation has not hitherto been analyzed experimentally. The reason for this state of affairs is probably that experiments involving stimulation of the cortex performed by the authors cited above were acute in nature and were carried out under general anesthesia. We have investigated the effects of electrical stimulation of the motor points of the cerebral cortex in dogs after lateral hemisection of the spinal cord in chronic experimental conditions without anesthesia.

EXPERIMENTAL METHOD

Experiments involving stimulation of the cortex were conducted on six adult dogs over a long period of time before and after hemisection of the spinal cord. To stimulate the cerebral cortex silver surface electrodes, 1 mm in diameter, were implanted through burr holes in the skull above the motor area of representation of the forelimb; the electrodes were in contact with the dura but did not injure it.

A rectangular pulse current from a type GIF stimulator was used: duration of pulse 0.2 millisec, frequency 60-80 cps, duration of stimulation 1-2 sec, intervals between periods of stimulation from 1 to 4 min and more. The test to determine the animal's reaction to stimulation of the corresponding cortical motor points was flexion of the contralateral forelimb at the elbow.

When 1.5-2 weeks had elapsed after implantation of the electrodes, the strength of stimulation causing threshold, moderate, and maximal flexion of the forelimb was measured. During the experiments the dogs were attached to a special stand which maintained the limbs in the normal position after hemisection of the spinal cord at a period when the dogs could not stand unaided. The movements of the forelimbs were recorded by means of rheostat detectors (for method, see M. Ya. Chirakov [6]) on the tape of a type MPO-2 loop oscillograph. Both implantation of the electrodes and hemisection of the spinal cord were performed under general anesthesia with morphine and thiopental. The experimental animals remained under observation for 1.5-8 months after hemisection of the spinal cord. The operation of lateral hemisection (right or left) of the spinal cord was performed 4-5 weeks after implantation of the electrodes at the level of the 2nd-3rd cervical segments (in the subsequent account the forelimb on the side of the hemisection will be called affected, the opposite healthy.

EXPERIMENTAL RESULTS

For approximately 3 weeks after lateral hemisection of the spinal cord, stimulation of the cortical motor points caused no movements of the affected limb. No movements appeared even when the stimuli were 2-3 times as strong as those producing maximal flexion before the operation. In the two younger dogs, however, approximately 1.5 weeks after hemisection, isolated feeble movements of the affected limb were seen. In the other dogs similar movements were seen at a later stage, when the dogs had begun to stand and tried to walk on three limbs (avoiding using the forelimb on the side of the hemisection), while only companion movements were observed in the affected limb. The first clear flexions of the affected limb could be elicited in the dogs 2-3 days before the time when the limb began to participate actively in standing and walking. As a rule this was observed at the end of the 3rd-4th week after hemisection of the spinal cord. Usually the first motor reactions were elicited only by powerful stimulation of the cortex; as the disturbed functions of standing and walking were restored in the affected limb, with each successive day movements could be produced by progressively weaker stimuli (Fig. 1).

The character of the movement elicited in the affected limb was not always one of flexion alone. Frequently extension was observed at first, followed by flexion. However, a motor response of the affected limb of this nature was produced only before the maximal level of restoration of the functions of standing and walking had been attained, i.e., approximately before the 45th-50th day after hemisection of the spinal cord. Furthermore, stimulation of the cortical motor points corresponding to the contralateral affected limb sometimes led to movement of the homolateral (healthy) limb, and only then did the affected limb begin to move. This complex bilateral response was observed also during the period of recovery of the disturbed functions of the affected limb. Movements of the healthy limb could be elicited on the 2nd day after hemisection; a very slight and transient increase in the duration of the latent period of the elicited movement was noted, and in some dogs it was necessary to increase the strength of cortical stimulation slightly to obtain the movement. In most dogs the healthy limb reacted just as before the operation after a period of 3-4 days (Fig. 2).

Prolonged observations on the experimental animals revealed a certain degree of constancy in the character of the motor reactions of the affected limb to stimulation of the cortical motor points of the contralateral hemisphere. Maximal flexion of the affected limb could be obtained regularly with stimulation of almost the same strength as that used before hemisection. However, it was difficult to elicit a smooth gradation of movements – threshold, moderate, and maximal flexion. During walking, the affected limb appeared to be functioning perfectly, whereas during electrical stimulation of the cortex its movements were always much smaller in amplitude than before hemisection.

As the disturbed functions of standing and walking were restored, the strength of stimulation of the cortical motor points required to elicit movements of the healthy limb gradually diminished (for example, in the dog Damka, from 7.5 to 5.3 V, in Pastila from 15.5 to 13 V, and in Smirnyi from 18 to 15 V). The latent period of the elicited movements of the affected limb was much longer than before the operation, and also much longer than the latent period of the motor reaction of the healthy limb (see Figs. 1 and 2). Hence, in chronic experimental conditions in dogs, limb movements may be observed in response to electrical stimulation of the corresponding points of the motor area of the cortex after lateral hemisection of the spinal cord.

The discrepancy between these results and those obtained by the workers cited above [10-12, 14] can possibly be explained by the fact that they carried out acute experiments in which, as É. A. Asratyan suggests, it is difficult or even impossible to reveal the conditioned connections, so delicate and so vulnerable to modifying influences, lying at the basis of development of compensatory adaptations.

Restoration of the disturbed functions of standing and walking evidently takes place as a result of the formation of conditioned connections; under these circumstances the collateral pathways (innervating the affected limb) become functionally more perfect under the influence of training.

It remains to be explained why the movements of the affected limb caused by stimulation were only about half the amplitude of those present before hemisection, whereas during walking the range of movements of the affected limb was the same as that of the healthy limb.

Restoration of disturbed functions may take place, firstly, by means of crossed pathways from the homolateral hemisphere, and secondly, by means of direct pathways from the contralateral hemisphere [2].

In natural conditions the restoration of the functions of the affected limb after hemisection takes place, apparently, on account of the activity of both hemispheres, but predominantly the homolateral hemisphere [3,4], so

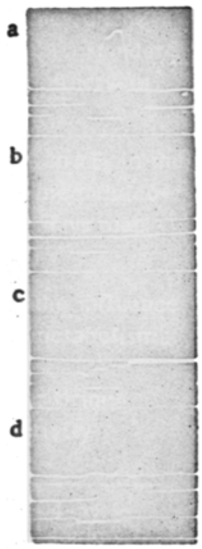

Fig. 1. Tracing of movements of the forelimbs of the dog Trusishka before (a) and 4 days (b), 19 days (c), and 81 days (d) after hemisection of the spinal cord on the left side at the level C_2-C_3. Significance of the curves (from above down): movement of the healthy limb; movement of the affected limb; marker of cortical stimulation; time marker (1 sec).

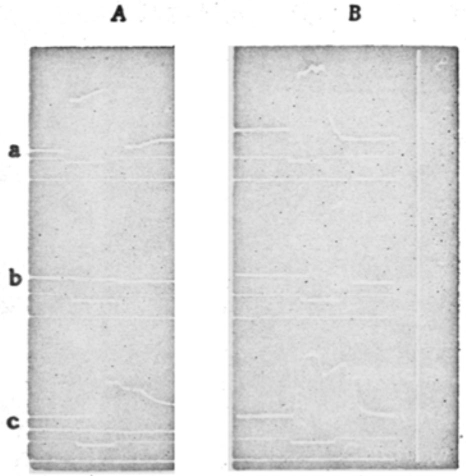

Fig. 2. Tracing of movements of the forelimbs of the dog Smirnyi before (a) and 4 days (b) and 39 days (c) after hemisection of the spinal cord on the left side at the level C_2-C_3. A) Movement of the left limb; B) movement of the right limb.

that a full range of movement of the limb may result. In the conditions of electrical stimulation of the cortex, however, the limb movements are brought about by the activity of the stimulated hemisphere only (in our case, by means of the direct pyramidal tracts of the contralateral hemisphere). Hence, the amplitude of the limb movements in response to electrical stimulation of the cortex is only half the amplitude observed in natural conditions. Hence, the explanation of this phenomenon which we submit is that in natural conditions the movements of the affected limb are activated by both hemispheres, and during stimulation of the cortex – by the stimulated hemisphere only.

SUMMARY

The effects of electric stimulation of the motor points of the cortex were studied in dogs following lateral hemisection of the spinal cord at the level of 2nd-3rd cervical segments. Chronic experiments were staged on 6 adult dogs without anesthesia. Superficial silver electrodes were implanted into trephined openings in the cranium over the motor area of the cortical representation of the fore limbs; this was done for stimulation of the motor points of the cortex. Stimulation of the cortex was first carried out prior to hemisection of the spinal cord, then 1-5 months later. For the first time it was shown that after the spinal cord hemisection it was possible to provoke movement in the affected extremity by stimulation of the corresponding motor points in the cerebral cortex. Such movement may be induced about 3-4 weeks after spinal cord hemisection, i.e., 2 to 3 days before the extremity begins actively to participate in standing and walking.

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