EFFECT OF BRAIN-STEM STIMULATION EVOKING LOCOMOTION ON ASCENDING REFLEXES IN THE MESENCEPHALIC CAT

N. N. Budakova and M. L. Shik

UDC 612.833.8

In experiments on curarized mesencephalic cats, stimulation of the brain stem which, before curarization, evoked stepping movements, increased the reflex response of the radial nerve to stimulation of the afferent fibers of the hind limb and shortened the latent period of this reflex.

Unlike the segmental reflexes of the spinal cord, relatively little is known regarding the long reflexes – those from limb receptors of one girdle to motoneurons of the other girdle – and their importance remains unexplained. The existence of interlimb reflexes has been known for a long time [3, 7, 14]. However, the electrophysiological analysis of these reflexes started much later [1, 2, 12, 13].

During the study of locomotion of dogs on a treadmill, indications were obtained of the essential importance of interaction between the limbs in movement coordination [4]. More direct data were obtained by the use of a preparation with guided locomotion [6]. It was shown that natural reflexes from the forelimbs on motoneurons of the hind limbs, which are absent in the mesencephalic cat, appear in response to stimulation of a part of the brain stem which, before curarization, evoked locomotion [5].

This observation suggested that interlimb reflexes play a role in locomotion, although the conditions under which they were elicited were such that it was impossible to estimate the latency of these responses.

The object of the present investigation was to determine whether ascending interlimb reflexes are strengthened during stimulation of the part of the brain stem, stimulation of which in the noncurarized mesencephalic cat evokes locomotion.

EXPERIMENTAL METHOD

Lumbar laminectomy was performed under ether anesthesia, and the dorsal root of L_7 was dissected for stimulation. In other experiments the peroneal, tibial, or sciatic nerve was dissected for stimulation and divided distally to the electrodes. The radial nerve and the nerve to the gastrocnemius muscle or deep peroneal nerve were dissected for recording.

The carotid arteries were ligated and precollicular decerebration carried out [6]. The anesthesia was stopped, and the experiment began 3 h later. The threshold strength of stimulation of the mesencephalic "locomotor region" to produce stepping movements was determined [6]. The animal was then immobilized by intravenous injection of D-tubocurarine (0.1-0.2 mg per cat), and artificial respiration was applied. The nerves and spinal cord were covered with mineral oil, and the cat's temperature maintained at 37°.

The dorsal root and nerve were stimulated, usually by a volley of 3-6 square pulses (duration of volley 5-9 msec; pulse duration 0.5 msec; voltage 0.5-4 V), at a frequency of once every 2 sec. In some cases

Interdepartmental Laboratory of Mathematical Methods in Biology, Moscow University. Laboratory of Movement Regulation, Institute for Problems in Information Transmission, Academy of Sciences of the USSR. (Presented by Academician V. V. Parin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 69, No. 1, pp. 7-11, January, 1970. Original article submitted July 4, 1969.

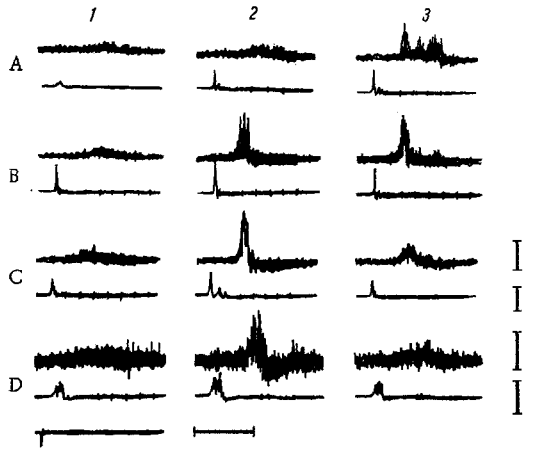

Fig. 1. Ipsilateral ascending and segmental reflexes evoked by application of a single stimulus to dorsal root L_7. Top beam shows response of radial nerve, bottom beam response of deep peroneal nerve. A: 1-3) Reflexes during stimulation of root in increasing strength (1/2 sec); B) effect of frequency of stimulation: 1) 1/2 sec, 2) 2/sec, 3) 1/2 sec again; C and D) effect of stimulation of brain stem: 1) before; 2) during; 3) after stimulation of brain stem. Strength of stimulation in B and C the same as in A2. Strength of stimulation in D the same as in A1. Time of application of stimulus shown below. Amplitude of calibration signal in D for top beam 20 μV, for bottom beam 250 μV. In remaining frames amplitude of calibration signal for top beam 50 μV, for bottom beam 1 mV. Time marker 20 msec.

single pulses were given at a frequency of 2/sec. The mesencephalon (Horsley–Clark coordinates P_2, Y_4, H_0) was stimulated through a bipolar electrode made from two varnished nichrome wires, 0.1 mm in diameter, glued together so that the distance between their tips was 0.5-1 mm. The frequency of stimulation was 30-40 pulses/sec and its voltage was 6-20 V.

Stimuli were generated by a stimulator with two independent outputs, built by Yu. B. Kotov. The stimulating pulses were applied through a dividing transformer. Electrical responses of the nerves were fed through a UBP1-02 biopotential amplifier with transmission band 10-2000 Hz to the plates of a CRO from the screen of which they were photographed. Usually five sweeps of the beam were superposed on one frame.

In 19 experiments the ipsilateral ascending reflex (AR) from the dorsal root of L7 to the radial nerve was recorded and in 12 experiments parallel recordings were made of responses of the ipsilateral nerve to the gastrocnemius muscle or the deep peroneal nerve. In addition, in 5 experiments the contralateral AR was studied. No significant differences were found between the ipsilateral and contralateral ARs.

EXPERIMENTAL RESULTS

The latent period of the AR was usually 15-17 msec, with possible variations from 10 to 30 msec. This response, usually scattered, lasted 10-12 msec. In some experiments a response with duration 12-16 msec was accompanied by less constant responses with latent periods of 20-26 and 30-40 msec. These late responses became visible when the strength of stimulation was adequate. Their amplitude was inconstant, but as a rule it was smaller than the amplitude of the short-latency response (Fig. 1A). The AR was evoked far more easily, and was stronger in response to stimulation of the dorsal root by a volley of pulses than to stimulation by a single pulse. Sometimes the AR increased considerably in amplitude during the experiment.

In 7 of the 14 preparations the AR was strengthened by a change in the frequency of stimulation from 1/2 sec to 2/sec (Fig. 1B). The latent period of the AR decreased from 11-20 to 9-16 msec. In 6 of these 7 experiments only the short-latency response was strengthened. After a return to less frequent stimulation the AR remained strengthened for several tens of seconds. Stimulation at 2/sec evidently can substantially modify the state of the central nervous system in the mesencephalic cat. The increase in strength of the AR was perhaps associated with coordination of the stepping movements, the rhythm of which in the running cat is about 2/sec.

In two experiments the latent period of the AR was shortened but the amplitude of the response did not increase, while in five experiments the amplitude fell as the frequency of stimulation rose.

Stimulation of the brain stem (of a strength less than or equal to that which, before curarization, evoked locomotion) strengthened the AR in 21 of 22 experiments. In most experiments strengthening of the short-latency component of the AR was observed (Fig. 1C), and this component could arise against the background of stimulation of the brain stem even if hitherto it had hardly existed at all (Fig. 1D). The latent period of the AR was reduced to 8-15 msec. In three experiments stimulation of the brain stem strengthened two components of the AR with latencies of 10-15 and 18-28 msec.

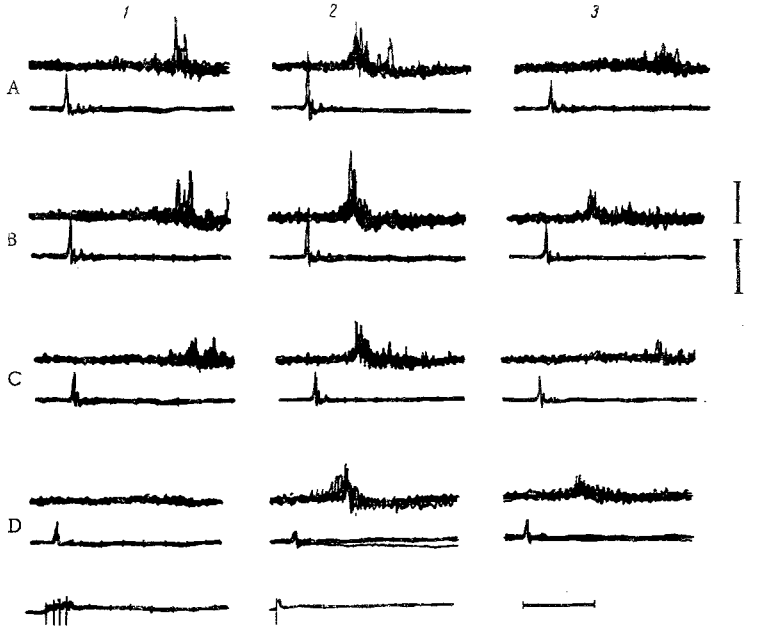

Fig. 2. Effect of stimulation of brain stem on ipsilateral ascending and segmental reflexes evoked by stimulation of the dorsal root of L_7. Top beam gives response of radial nerve, bottom beam response of nerve to gastrocnemius: 1) before, 2) during, and 3) after stimulation of brain stem; A-C) stimulation applied as a volley of pulses; D) as a single pulse. Calibration signal for top beam 50 μV; for bottom beam 1 mV. Time marker 20 msec.

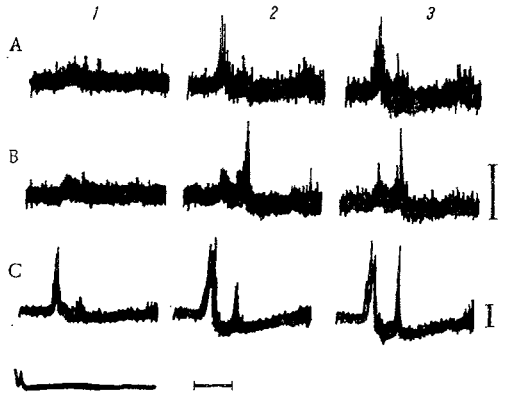

Fig. 3. Reflex of radial nerve in response to stimulation of ipsilateral peroneal nerve. A) Effect of frequency of stimulation: 1) at 1/2 sec; 2, 3) at 2/sec; B, C) effect of stimulation of brain stem: 1) before, and 2, 3) during stimulation of brain stem. Afferent stimulation in B and C applied at 1/2 sec. Calibration signal 20 μV. Time marker 20 msec.

In six experiments not only the AR but also the segmental reflex was strengthened during stimulation of the brain stem (Fig. 1C). However, even if the strength of afferent stimulation was submaximal for the segmental reflex, stimulation of the brain stem could increase the AR significantly more than the segmental reflex (Fig. 1D).

In four experiments the segmental reflex either was inhibited by or did not respond to stimulation of the brain stem, and sometimes inhibition of the reflex appeared to alternate with its strengthening. A few examples of the effect of brain-stem stimulation, taken from one such experiment, are illustrated in Fig. 2. It is clear that in all four tests the AR was increased by stimulation of the brain stem and that its latent period was shorter than in the background period. The reflex response in the nerve to the gastrocnemius muscle was inhibited in some sweeps of the beam, and in others it was strengthened (A, B); in C its amplitude was unchanged, and in D it was inhibited by stimulation of the brain stem.

In two experiments the AR was recorded parallel with the polysynaptic reflex of the nerve to the gastrocnemius muscle. The latter reflex was unchanged by stimulation of the brain stem, while the AR was strengthened.

In four experiments the diagonal AR was investigated parallel with the crossed reflex of the nerve to the gastrocnemius. During brain-stem stimulation the AR always increased more than the crossed segmental reflex. In one experiment an increase in strength of the AR was accompanied either by inhibition or by facilitation of the crossed segmental reflex.

In 17 experiments the AR was evoked by stimulation of peripheral nerves (the common peroneal, sciatic, or contralateral tibial nerve). Stimulation of these nerves gave very similar results to those obtained by stimulation of the dorsal root. This applies both to the latent period and shape of the ARs and to their ability to be strengthened during stimulation of the brain stem and during an increase in the frequency of afferent stimulation. Strengthening of a weak AR in response to a change in the frequency of stimulation to 2/sec (A) and to stimulation of the brain stem (B) is illustrated in Fig. 3. In the latter case two components of the response become clearly visible. In the course of the experiment the AR increased (C). Stimulation of the brain stem strengthened this increased AR still more. Stimulation of the brain stem could also strengthen an AR evoked by stimulation at 2/sec.

The scattered character of the AR or its consisting of two components could be due to the existence of two systems of long reflexes: propriospinal and spinobulbospinal [9, 10, 15, 16]. If the two factors ("locomotor" frequency of afferent stimulation and stimulation of the brain stem of the sort which, before curarization, evoked stepping movements) were present, the AR was strengthened and became more synchronous, and the time required for interaction between the limbs was shortened. These observations are in agreement with the hypothesis that interlimb reflexes play an important role in locomotion.

Strengthening of the AR in response to stimulation of the "locomotor region" of the mesencephalon cannot be explained simply by diffuse facilitation of motoneurons. First, strengthening of the AR is associated with shortening of its latent period by 1-4 msec (and in some cases by 10 msec). The shortening of the latency is evidently explained by descending influences on the interneurons of this polysynaptic reflex (see also [8, 11, 17]). Second, in some cases an increase in strength of the AR was not accompanied by strengthening of the segmental reflex, and sometimes the latter reflex was actually inhibited by brainstem stimulation. It may therefore be considered that stimulation of the "locomotor region" of the brain stem in the immobilized animal evokes a coordinated, rather than diffuse, change in the state of the various interneuronal systems of the spinal cord.

LITERATURE CITED

1. N. A. Adamovich and A. N. Borgest, Fiziol. Zh. SSSR, No. 7, 787 (1968).
2. T. K. Ioseliani, G. I. Machavariani, and K. G. Chokheli, Fiziol. Zh. SSSR, No. 7, 823 (1966).
3. I. M. Sechenov, Selected Works [in Russian], Vol. 2, Moscow (1956), pp. 533, 543.
4. M. L. Shik and G. N. Orlovskii, Biofizika, No. 6, 1037 (1965).
5. M. L. Shik, G. N. Orlovskii, and F. V. Severin, Biofizika, No. 5, 879 (1966).
6. M. L. Shik, F. V. Severin, and G. N. Orlovskii, Biofizika, No. 4, 659 (1966).
7. N. I. Shumilina, Fiziol. Zh. SSSR, No. 5-6, 272 (1945).
8. I. Engberg, A. Lundberg, and R. W. Ryall, J. Physiol. (London), 194, 225 (1968).
9. B. E. Gernandt and D. Megirian, J. Neurophysiol., 24, 364 (1961).
10. B. E. Gernandt and M. Shimamura, J. Neurophysiol., 24, 665 (1961).
11. K. Koizumi, J. Ushiyama, and C. Brooks, Jap. J. Physiol., 9, 282 (1959).
12. D. P. C. Lloyd, J. Neurophysiol., 5, 435 (1942).
13. D. P. C. Lloyd and A. K. McIntyre, J. Neurophysiol., 11, 455 (1948).
14. C. S. Sherrington, J. Physiol. (London), 22, 319 (1898).
15. M. Shimamura and R. B. Livingston, J. Neurophysiol., 26, 258 (1963).
16. M. Shimamura and K. Akert, Jap. J. Physiol., 15, 638 (1965).
17. I. Suda, K. Koizumi, and C. Brooks, J. Neurophysiol., 21, 113 (1958).
18. F. H. Thiele, J. Physiol. (London), 32, 358 (1905).