SHORT-LATENCY INTERSTITIOSPINAL AND RUBROSPINAL SYNAPTIC INFLUENCES ON α-MOTONEURONS

A. I. Shapovalov and O. A. Karamyan

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Experiments on cats, in some of which the red nucleus, the nucleus of Cajal, or the superior colliculi had first been destroyed, demonstrated the presence of short-latency interstitiospinal and rubrospinal synaptic projections of motoneurons. Many of the short-latency EPSPs and IPSPs are disynaptic in character, but in some cells monosynaptic EPSPs were recorded.

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The rubrospinal and interstitiospinal tracts in mammals join the mesencephalon directly to caudal divisions of the spinal cord [5, 8, 9, 12]. Rubrospinal impulses can excite the lumber motoneurons of cats with a very short latent period, on the basis of which the existence of mono- and disynaptic projections is assumed [4, 6, 10]. Interstitiospinal synaptic influences on spinal cord neurons have not yet been investigated.

The object of this investigation was to study the character of both rubrospinal and interstitiospinal effects. To increase the probability of isolated stimulation of the various structures by electrodes implanted into the brain, some experiments were carried out on animals after preliminary destruction of the red nucleus, the interstitial nuclei of Cajal, or the tectum mesencephali.

EXPERIMENTAL METHOD

Experiments were carried out on 27 cats lightly anesthetized with nembutal. In 3 animals the contralateral red nucleus was destroyed by electrocoagulation 10-20 days before the experiment, in 2 animals the interstitiospinal tract was destroyed bilaterally, together with the contralateral nucleus of Cajal, and in one animal the superior colliculi were destroyed bilaterally. Stimulating bipolar electrodes, with interpolar distance 0.1-0.3 mm, were introduced stereotaxically into the brain, and their location was subsequently verified histologically. Square pulses, 0.1-1 mA in strength and 0.2-0.3 msec in duration were used for stimulation. Excitatory and inhibitory postsynaptic potentials (EPSPs and IPSPs) of the motoneurons of the lumbar enlargement were recorded intracellularly. Parallel recordings were made of the potentials of the dorsal surface of the spinal cord (DSP). The motoneurons were identified by stimulation of the ventral roots or nerves supplying the muscles (nerves to the gastrocnemius, plantaris, biceps-semitendinosus, the deep peroneal nerve, and the nerve to flexor hallucis longus).

EXPERIMENTAL RESULTS

Responses to stimulation of the interstitial nucleus of Cajal were recorded in 140 motoneurons, of which 92 gave EPSPs and 30 IPSPs, while in 18 mixed responses were observed; 72 cells responding to interstitiospinal impulses were identified from their responses to stimulation of the muscular nerves. In 39 of 42 flexor motoneurons EPSPs were found, and IPSPs in the other 3. In 17 of the 30 extensor motoneurons EPSPs were recorded, IPSPs in 7 and mixed responses in 6.

As the histogram (Fig. 1B) shows, many of the interstitiospinal EPSPs were characterized by a short latent period, with maximum between 4 and 7 msec. Short-latency EPSPs could develop even in response to single stimuli. However, in most cases repeated stimulation (2-3 pulses) was required for a distinct response to appear. The shortest latent periods of the EPSPs were 3.5-3.6 msec. The minimal latent period of the IPSP was 1-2 msec longer than the latent period of the short-latency EPSPs.

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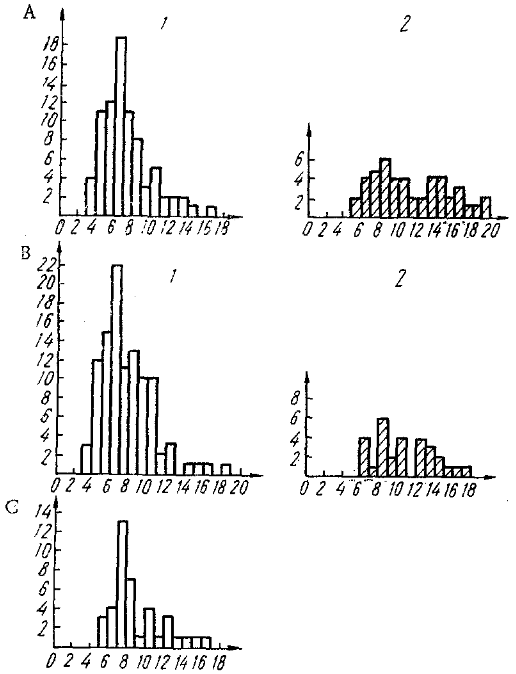

Fig. 1. Distribution of latent periods of EPSPs (1) and IPSPs (2) of motoneurons in response to stimulation of contralateral red nucleus (A), interstitial nuclei of Cajal (B), and tectum (C). Abscissa, latent periods (in msec); ordinate, number of neurons.

Segmental delay, determined from the interval between the initial component of the DSP and EPSP, was less than 1 msec in two cells, indicating monosynaptic transmission. In all other cases the duration of segmental delay was more than 1.1 msec. In many cells giving short-latency responses the segmental delay did not exceed 2.2-2.3 msec, indicating the disynaptic character of the corresponding effects.

By recording the DSPs and antidromic responses in the region of the nucleus of Cajal during stimulation of the ventrolateral part of the spinal cord at the level L6-7, the conduction velocity along the interstitiospinal tract was determined as 115 m/sec. Comparison of the conduction velocity with the latent periods of responses of the motoneurons likewise indicated the existence of monosynaptic and, in particular, disynaptic interstitiospinal effects.

Responses to stimulation of the red nucleus were recorded in 135 motoneurons: EPSPs in 81, IPSPs in 50, and mixed effects in 4. All 22 flexor motoneurons responded with EPSPs. In 14 of 27 extensor motoneurons IPSPs were observed, EPSPs in 9, and mixed responses in 4.

The distribution of latent periods of the rubrospinal EPSPs and IPSPs (Fig. 1A) was very similar to the results obtained during stimulation of the nucleus of Cajal (Fig. 1B). In two cells, giving rubrospinal EPSPs with latent periods of 3.6 and 3.9 msec, the duration of segmental delay showed that they were definitely monosynaptic in nature. Most short-latency rubrospinal EPSPs, and also some IPSPs, could be classed as disynaptic responses. The conduction velocity along the rubrospinal tract, measured from the appearance of the initial component of the DSP or antidromic wave in the region of the red nucleus reached 110 m/sec. These results correspond to those obtained by more precise measurement of the conduction velocity along the rubrospinal axons by means of intracellular recording of antidromic responses in rubrospinal neurons [11] and they confirm the conclusion that EPSPs of motoneurons are monosynaptic and disynaptic in character.

Tectospinal impulses evoked EPSPs in all flexor (13 cells) and most extensor (in 12 of 13) motoneurons. However, the latent period of the responses was not less than 5 msec (Fig. 1C).

Preliminary destruction of the tectum, the nuclei of Cajal, or the red nucleus did not cause lengthening of the latent periods of the interstitiospinal or rubrospinal responses. Hence, responses obtained to stimulation of the corresponding structures did not involve the participation of neighboring structures.

However, EPSPs with latent periods of 4.1-6.4 msec were also obtained when the stimulating electrodes penetrated into the region of the central segmental tract. It may be assumed that the effects observed in such cases may be associated with stimulation of ascending axons of reticulospinal neurons with projection into the region [7, 13].

The amplitude of responses to single interstitiospinal and rubrospinal impulses was small, usually not more than 1-2 mV. However, short repetitive stimulation considerably increased the amplitude of the response to the motoneuron. This property was evidently due largely to potentiation developing in the course of stimulation. When paired stimuli were used, enabling changes in amplitude of the second response relative to the first to be assessed quantitatively depending on the interval between them, it was found that the degree of potentiation could reach 300-400%. The most marked potentiation developed with intervals of 3-10 msec. It was observed during both interstitiospinal and rubrospinal effects, and in the case of IPSPs as well as EPSPs (Figs. 2 and 3). Potentiation was absent or negligible in the case of monosynaptic EPSPs (Fig. 2D) and was characteristic of disynaptic responses. In the course of potentiation, the latter increased parallel with the relay component of the DSP, reflecting activation of propiospinal interneurons [3].

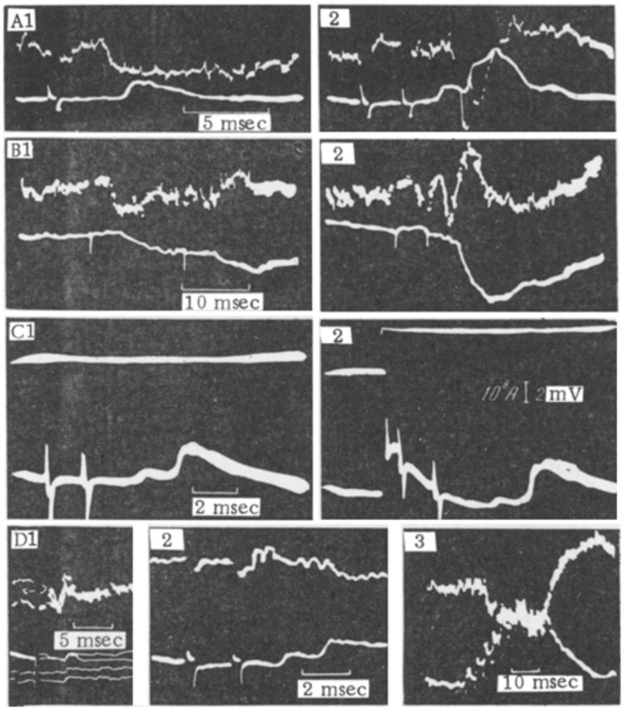

Fig. 2. Disynaptic (A, B, C) and monosynaptic (D) interstitiospinal (A, B) and rubrospinal (C, D) postsynaptic potentials. A) Responses to single (1) and paired (2) stimuli 0.4 mA in strength; B) responses to paired stimuli (0.5 mA) at different intervals (1, 2); C) responses to paired stimuli (0.7 mA) before (1) and during (2) passage of hyperpolarizing current; D) monosynaptic EPSPs in response to single (1), paired (2), and repetitive (3) stimulation 0.4-0.5 mA in strength. On all frames, bottom curve denotes intracellular recording, upper curve: in A, B, D) DSP, in C) record of current passed through cell.

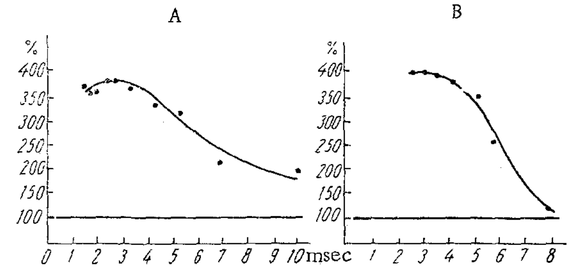

Fig. 3. Potentiation of interstitiospinal (A) and rubrospinal (B) EPSPs in response to paired stimulation. Relationship between potentiation of second response and interval between stimuli. Abscissa, interval between stimuli (in msec); ordinate, amplitude of second EPSP as percentage of first.

The potentiated disynaptic EPSPs were increased by the action of artificial hyperpolarization of the cell membrane. This property, which also distinguishes them from monosynaptic rubrospinal EPSPs [4], is evidence that the corresponding synapses are situated in the region of the soma and proximal dendrites of the motoneuron. Further evidence of this is provided by the rapid temporal course of disynaptic EPSPs, frequently having a very short ascending phase 0.5-0.6 msec) and rapid decline (time constant up to 2.5-3 sec). However, the phenomena observed could also be explained by linkage of an inhibitory fraction with the EPSP.

The results thus show that interstitiospinal and rubrospinal effects may reach lumbar motoneurons with a very short latent period; an important part of the short-latency influences is effected through disynaptic pathways, although monosynaptic rubrospinal and interstitiospinal excitation of motoneurons is also possible. A characteristic feature distinguishing disynaptic effects is frequency-linked potentiation, similar to the potentiation found by investigation of other direct descending projections: vestibulospinal and reticulospinal [1, 2]. Consequently, descending systems differing in their function and projections in the spinal cord utilize similar mechanisms for transmission of the most urgent synaptic effects.

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