Motor Cortical Modulation of the Macaque Red Nucleus*

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Summary. The nuclei of the neocerebellum receive inputs from somatosensory receptors and the motor cortex. In cats, the discharge of those nuclear neurons which were driven by passive movement of a limb segment in one direction was suppressed by stimulation of the cortical site from which movement was evoked in the opposite direction (Larsen and Yumiya 1979a). The cortical-evoked suppression of cerebellar neurons resulted in a disfacilitation of red nucleus neurons whose discharge elicited movement in the same direction as the cortical neurons from which the suppression was evoked and which were driven by passive movement in the opposite direction (Larsen and Yumiya 1980a). The purpose of this study was to determine if the cortical modulation of rubral neurons is organized in macaque monkeys in the same way as it is in cats. Red nucleus neurons were characterized by their response to natural stimulation of somatosensory receptors, and their response to cortical microstimulation was examined in peristimulus time histograms (PSTHs). Cortical stimulation evoked a short-latency corticorubral facilitation and a longer latency response which was presumed to be mediated by the cerebellum and which was composed primarily of suppression but was sometimes preceded by a brief facilitation. As was true in cats, over half of the rubral neurons which were driven by passive movement of a limb segment in one direction responded with a facilitation-suppression to stimulation of the “agonistic” cortical site from which movement was evoked in the opposite direction, but only a few responded to stimulation of the “antagonistic” cortical sites. Similar responses were evoked in many rubral neurons by stimulation of other cortical sites from which movement was elicited about the same joint in a different plane or at a joint adjacent to that whose passive movement drove the rubral neuron. Responses were found in neurons which received somatosensory input from proximal or distal limb segments and in neurons in the parvocellular or magnocellular divisions of the nucleus, although the corticorubral facilitation was found more frequently in parvocellular neurons. In conclusion, the motor cortical modulation of the red nucleus and cerebellum is similar in monkeys and cats, and is the same for the proximal and distal limb representation.

Key words: Motor cortex – Red nucleus – Cerebellum – Monkey

The organization of the convergence of inputs from somatosensory receptors with those from the motor cortex onto neurons in the intermediate and lateral cerebellar nuclei in cats was reported recently (Larsen and Yumiya 1979a). Many of the cerebellar nuclear neurons were driven by passive movement of one or two limb segments in one direction and their discharge was suppressed by stimulation of cortical sites from which movement was evoked in the opposite direction. This suppression of discharge was also found in the red nucleus, a target of the cerebellum, in neurons which facilitated movement in the same direction as the cortical neurons from which the suppression was evoked (Larsen and Yumiya 1980a). Furthermore, a cerebellar-mediated facilitation was elicited by high velocity stretch of a muscle in neurons in the cortical area from which contraction of that muscle was evoked (Murphy et al. 1975). On the basis of these results, a model was

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proposed (Larsen and Yumiya 1979a, 1980a) in which the discharge of cerebellar nuclear neurons was suppressed by activation of the motor cortical neurons which they facilitate. The purpose of this study is to determine if the presumably cerebellar-mediated suppression of discharge is evoked by cortical stimulation in primate rubral neurons with an organization similar to that found in cats. Furthermore, in view of the well developed ability of primates to use digits independently, it is of interest to compare the responses of rubral neurons which receive an input from the distal limb with those which receive an input from proximal limb segments.

The rubrospinal and rubroolivary axons in cats arise from neurons with an overlapping distribution or from branches of the same axon. The rubral neurons which were activated antidromically from the spinal cord of cats as well as those which were not, had somatosensory receptive fields (Larsen and Yumiya 1980a). Unlike rubral output in cats, the rubrospinal and rubroolivary axons in monkeys arise from different parts of the red nucleus. As in cats, however, neurons in the parvocellular division of the primate red nucleus (RNpc), the origin of the rubroolivary tract (Massion 1967; Miller and Strominger 1973; Strominger et al. 1978), had somatosensory inputs indistinguishable from those in the magnocellular (RNmc) division of the nucleus (Larsen and Yumiya 1980b), the origin of the rubrospinal tract (Castiglioni et al. 1975; Massion 1967; Miller and Strominger 1973). Since both antidromically identified and unidentified rubral neurons in cats had similar responses to motor cortical stimulation, another purpose of this study in monkeys is to compare the responses evoked in RNmc neurons by cortical stimulation with those evoked in RNpc neurons.

We will show that the motor cortical modulation of the macaque red nucleus and cerebellum is similar to that reported in cats. Stimulation of a cortical site from which movement of a limb segment is evoked in one direction elicits in rubral neurons driven by passive movement of that limb segment in the opposite direction a presumably corticorubral facilitation followed by cerebellar-mediated suppression of discharge. This same response pattern was found in RNpc and RNmc neurons and in neurons with an input from proximal and distal limb segments. A preliminary report has appeared (Larsen and Yumiya 1979b).

**Methods**

The responses of red nucleus neurons to motor cortical stimulation were examined in four cynomolgous monkeys (*Macaca fascicularis*) using the same technique as that for studying feline red nucleus and cerebellar neurons (Larsen and Yumiya 1979a, 1980a). The somatosensory input to the same rubral neurons which are the subject of this report was described in a separate publication (Larsen and Yumiya 1980b). Two chambers were placed over holes in the skull, one to allow an array of eight stimulating electrodes to be inserted into the motor cortex at a depth of 1 mm, and the other to direct microelectrodes toward the red nucleus. All surgical procedures were conducted either on the day of the experiment or the day before under halothane-nitrous oxide anesthesia, but the animals were completely unanesthetized for the experiment. They were usually alert and strong and accepted food and juice, but occasionally became drowsy. The animals were seated in a primate chair for the experiment with the head immobilized by means of bolts secured to the skull with acrylic cement.

Long trains of 12, 0.2 ms stimulating pulses were delivered through the cortical electrodes at the beginning of the experiment (2 h after implanting the electrodes and discontinuing the anesthesia) to evoke movements and thereby identify each cortical site. These twelve-pulse trains were 40 ms in duration and were given at a 0.3 Hz repetition rate. Each pulse had a maximal amplitude of 20 microamps (μA) monitored as the IR drop across a 10 kΩ resistor.

Red nucleus neurons were recorded extracranially with tungsten-in-glass microelectrodes (Stoney et al. 1968). The receptive field of each neuron was identified by activating first cutaneous and then deep receptors. When the discharge of a neuron was increased by passively rotating a joint in one direction, for example extension of the elbow, and decreased by rotating in the opposite direction, then the cell was said to be driven by the passive movement which caused the increase (elbow extension). The response of individual neurons to motor cortical stimulation was determined by constructing peri-stimulus time histograms (PSTHs) with the aid of a Nicolet A1072 (Nicolet Instrument Co.) signal averager. All latencies were measured from the first stimulus pulse. As has been discussed already (Larsen and Yumiya 1980b), some latencies may be shorter than reported if they arose from the second or third pulse, but this will not affect the interpretation of results. A window discriminator was used to isolate spikes in multi-unit records and to generate pulses which were led to the signal averager. Sixty-four, three pulse trains with 20 μA per pulse were delivered to the motor cortex at a 1 Hz repetition rate to construct the PSTHs. Neuronal discharge was recorded (Teac A2340) on magnetic tape (Scotch AV 177) and the PSTHs compiled after the experiments. Finally, long stimulus trains were delivered in the same manner as in the motor cortex to evoke movements from the red nucleus. Small lesions were made to mark recording sites by passing 10 μA of cathodal current for 10 s.

After the experiments the animals were anesthetized and perfused with physiological saline followed by 10% formalin. The brains were blocked and stored in 30% sucrose and 10% formalin. Sagittal sections were cut on a freezing microtome and stained using the Klüver and Barrera (1953) technique. Lesions were used to locate and reconstruct electrode penetrations, examples of which were illustrated by Larsen and Yumiya (1980b).

**Results**

The somatosensory responses of 208 neurons histologically verified to be in the red nucleus were studied with natural stimulation in six sides of four cynomolgous monkeys. The sensory input to these neurons and their microstimulation-evoked motor output has been reported elsewhere (Larsen and Yumiya 1980b). The response to motor cortical stimulation