Effects of Afferent Inputs from Mechanical and Nociceptive Receptors in the Footpads on the Monosynaptic Reflex in the Spinalized Cat

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Abstract. We previously reported that the effects of footpad stimulation on the monosynaptic reflexes (MRs) in the cat's lumbar spinal cord depend on stimulated footpad. In this study, the effects of different types of stimulation (tonic pressure, phasic pressure, squeezing and radiant heating at 50°C) on MRs were studied in 12 adult cats spinalized at T11-12. The effects of tonic pressure were very weak or not detected. The pattern for the effects of phasic pressure was similar to that for squeezing, but the effects of squeezing was stronger than those of phasic pressure. These results indicate that the effects of mechanical stimulation were mainly induced from phasic afferent inputs. Radiant heating was effective, and differential effects between mechanical stimulation and radiant heating were observed in some MRs. Our results suggest a difference in neuronal pathways from various types of receptors in the footpads.

Key words: feline, footpad, monosynaptic reflex, sensory receptor.


A previous paper reported that the effects of electrical stimulation to the footpad on the monosynaptic reflex varied depending on the part of the stimulated footpads [5]. These results suggested that afferent inputs from the footpads modulated motoneuronal activities to maintain the stability of the hindfoot. Janig et al. [2, 3] described the physiological characteristics of three types of mechanical receptors in the footpads. Furthermore, Behrends et al. [1] reported the effects of nociceptive stimulation to footpads on motoneuronal activity. The electrical stimulation employed in the previous paper [5] could not selectively stimulate different types of receptors in the footpads. In this study, the effect of stimulating of mechanical and thermoneuicide receptors on the monosynaptic reflex of various hindlimb motoneurons in the cat were studied to clarify the effects of afferent inputs from various types of receptors in the footpads.

Materials and Methods

Experiments were performed on 12 adult cats, weighing 2.4-4.5 kg. Cats were anesthetized with alpha-chloralose (i.v. 50 mg/kg). The spinal cord was transected at T10-11. The animals were immobilized with gallamine triethiodide and artificially ventilated. The End-tidal CO₂ concentration was monitored and maintained close to 4% by adjusting the tidal volume or ventilation rate. Blood pressure was monitored and maintained above 80 mmHg. Rectal temperature was monitored and maintained approximately at 37+1°C by a heating mat. The L7 and S1 ventral roots on the left side were cut and the proximal ends were mounted on silver electrodes for recording. The following muscle nerves of the left hindlimb were cut and the proximal ends were mounted on silver electrodes for stimulation: the posterior tibial nerve (PTN), the medial gastrocnemius (MG), the lateral gastrocnemius and soleus (LGS), the plantaris (Pl), the popliteus (Pop), the flexor digitorum longus (FDL), the tibialis anterior (TA), the peroneus longus (Per. 1), the peroneus brevis and tertius (Per. b+t), the extensor digitorum longus (EDL), and the plantar section of the tibial nerve (Tib). Each nerve was electrically stimulated with a single square wave (0.1 ms duration) to induce the monosynaptic reflex. The stimulus strength was adjusted to five times the threshold determined from an incoming volley recorded by a monopolar electrode placed on the L6 or L7 dorsal root. Different types of stimulation were applied to the footpad of the left hindfoot. Tonic pressing of the footpad (tonic pressure) was performed manually using a plastic stick (tip diameter 5 mm). Phasic pressing (5 Hz) (phasic pressure) of the footpad was performed by an electromagnetic vibrator (tip diameter 3 mm) with a triangular waveform with a rising and falling phase of 3 mm. Squeezing the footpad was performed with a forceps. Radiant heat was performed using a lamp heating system at 50°C while monitoring the temperature of the footpad surface by a temperature sensor placed on the footpad. Eight monosynaptic reflexes (MRs) recorded from the L7 ventral root were averaged by a signal processor (7117, NEC San'e). The magnitude of the MR was defined as the area of the averaged MR potential. The effect of conditioning stimulation on MRs was expressed in terms of percent control. When the MR size after each stimulation fluctuated or was small, the results were eliminated, since Kuno [4] reported that the degree of inhibition depended on the MR size. Differences in the strength of conditioned stimulus effect of the MR were analyzed significance using the Student t-test (p<0.05).

Results

Figure 1 illustrates the effects of phasic pressure on the central pads (CP) on the monosynaptic reflex induced by electrical stimulation of the Plantaris muscle nerve (PI-
MR) (Fig. 1a) and that on the toe pad-5 (TP-5) (Fig. 1b). The P1-MR was enhanced by phasic pressure on the CP and inhibited by phasic pressure on TP-5. At the bottom of figure 1, the arrangement of the footpad is shown.

Figures 2, 3 and 4 show the effects of footpad stimulation on the MRs of various hindlimb motoneurons.

Tonic pressure (data not shown): The effects of tonic pressure on the footpads were not observed or very weak in most cats.

**Phasic pressure (Fig. 2):** The posterior biceps and semitendinosus-MR (PBSt-MR) was enhanced by phasic pressure on the CP, while the effects of phasic pressure on the TPs were not remarkable.

The medial gastrocnemius-MR (MG-MR) and the lateral gastrocnemius and soleus-MR (LGS-MR) were inhibited by phasic pressure on the CP, TP-5, 4, 3 and 2, the inhibitory effects of phasic pressure on the TP-5 and on the CP tended to be stronger than those on other footpads.

The P1-MR was enhanced by the CP stimulation. The P1-MR was inhibited by phasic pressure on the TP-3 and 4, but the effect of phasic pressure on the TP-2 and 5 was not statistically significant.

Phasic pressure on the CP, TP-5 and TP-4 enhanced the popliteus-MR (Pop-MR), while phasic pressure on TP-2 and 3 did not have any significant effect.

Remarkable facilitation of the flexor digitorum longus-MR (FDL-MR) was induced by phasic pressure on the CP, while the effects of phasic pressure on the TPs were weak.

Phasic pressure on the CP inhibited the tibialis anterior-MR (TA-MR). The effect of the TP stimulation varied depending on which the TP was stimulated. The TA-MR tended to be inhibited by phasic pressure on the lateral TPs (TP-5, 4), and enhanced by that on the medial TPs (TP-3, 2).

The extensor digitorum longus-MR (EDL-MR) was enhanced by phasic pressure on the CP. Phasic pressure on the TP-5 and TP-4 inhibited the EDL-MR, but that on

![Figure 1. The effects of phasic pressure (right column) of the CP (a) and TP-5 (b) on the P1 monosynaptic reflex (MR). The P1-MR was enhanced by CP stimulation and inhibited by TP5 stimulation. The arrangement of central pad (CP) (right) and toe pad (TP) (left) is shown at the bottom. Abbreviation: CP; central pad, TP; toe pad.](image1)

![Figure 2. Effect of phasic pressure on MRs of various hindlimb motoneurons. Each dot indicates the mean of 5 experiments and vertical bars indicate the standard error. Vertical axis; degree of the effects of phasic pressure (control %), Horizontal axis; stimulated footpads. See text for detail. PBSt; posterior biceps and semitendinosus. MG; medial gastrocnemius. LGS; lateral gastrocnemius and soleus, Pl; plantaris. Pop; popliteus, FDL; flexor digitorum longus. TA; tibialis anterior, EDL; extensor digitorum longus, Per. l; peroneus longus, Per. b+t; peroneus brevis and tertius, Tib; the plantar section of the tibial nerve.](image2)
the other TPs showed no significant effect.

The effect of phasic pressure was very strong on the peroneus longus (Per. 1) and the peroneus brevis and tertius (Per. b+t)-MRs. These MRs were enhanced by phasic pressure on the CP and the lateral TPs (TP-5 and -4), and inhibited by phasic pressure on the medial TPs (TP-2 and -3).

The effect of phasic pressure on the MR of motoneurons innervating the plantar section of the tibial nerve (Tib-MR) was weak and inhibition was statistically significant only for phasic pressure on TP-2.

Squeezing (Fig. 3): In general, the effects of squeezing were stronger than those of phasic pressure, but these two stimuli produced similar pattern of effects on various MRs.

On the PBSt-, MG- and LGS-MRs, squeezing and phasic pressure produced similar effects.

The Pl-MR was markedly enhanced by squeezing the CP and inhibited by squeezing the TPs. Inhibitory effects caused by the TP-3 and 4 stimulation were stronger than those caused by the TP-2 and 5 stimulation.

The Pop-MR was facilitated by stimulating the CP, TP-5, and -4, and -3, while the effects of the TP-2 stimulation were not statistically significant.

The FDL-MR was enhanced by the CP stimulation. Inhibitory effects were induced by squeezing the TP-2 and TP-3, but not by phasic pressure on the footpads.

The patterns of effects from squeezing on the TA-, EDL-, Per.l- and Per. b+t-MRs were similar to those from phasic pressure. The effects of squeezing were stronger than those of phasic pressure.

The Tib-MR was enhanced by squeezing the CP, while inhibited from squeezing the TPs, but the inhibitory effects by phasic pressure were not remarkable.

**Radiant heating at 50°C (Fig. 4):** Figure 4 shows the effects on MRS at 50°C on MRs. The PBSt-MR was enhanced by radiant heating of the CP, TP-5 and -2. Facilitation by the TP stimulation was clearly demonstrated only with radiant heating. The effects of radiant heating on the MG- and LGS-MRs were similar to those of mechanical stimulation.

The Pl-MR was facilitated by the CP stimulation, while difference in the degree of effects from the TP-5 and TP-2 stimulation was statistically significant. This was not observed for mechanical stimulation.

The Pop-MR was enhanced by the CP and TP-5 stimulation and the effect of the TP-2 stimulation was not statistically significant. This was also observed for phasic pressure and squeezing.

The FDL-MR was enhanced by the CP and TP-5 stimulation and inhibited from TP-2 stimulation. In the TA-MR, the pattern of effects from radiant heating were very similar to that from squeezing.

Radiant heating of the CP and TP-5 inhibited the TA-MR, while that on the TP-2 enhanced the TA-MR. This pattern of effects was the same as that for squeezing.

The effects of radiant heating on the EDL-MR were very weak and a difference between the effects of the TP-5 and TP-2 stimulation, which was observed for mechanical stimulation, was not detected.

The effects of radiant heating on the Per. l-MR and Per. b was not as strong as those of mechanical stimulation.

The Tib-MR was enhanced by the CP radiant heating and inhibited by TP-2 stimulation.

**Fig. 3.** Effects of squeezing on MRS. Each dot indicates the mean of 5 experiments and vertical bars indicate the standard deviation. See text for detail.
DISCUSSION

The previous report showed that the effects of foot-pad stimulation on monosynaptic reflexes induced from various hindlimb motoneurons varied depending on the part of the footpad stimulated. This fact suggested the physiological role of afferent input from the footpad [5]. The aim of this study is to clarify the effects of afferent inputs from different types of receptors in the footpad on monosynaptic reflexes (MRs). Janig et al. [2, 3] classified footpad mechanoreceptors into three types: rapidly adapting receptors, slowly adapting receptors and pacinian capsule like receptors. Tonic pressure is considered to mainly activate slowly adapting receptors, phasic pressure activates all three types of receptors, and squeezing stimulates nociceptive receptors in addition to these three types of receptors. Behrends et al. [1] reported the effects of stimulating nociceptive receptors by radiant heating above 45°C on motoneuronal activity. When the radiant heating below 40°C was performed, no effects were detected (data not shown). Effects from radiant heating at 50°C may induce by afferent inputs from the thermonecicptive receptors.

There were no effects from tonic pressure, while phasic pressure had significant effects on the MRs. This fact suggests that the effects of pressure on the footpad were induced by phasic afferent inputs from the rapidly adapting and pacinian capsule like receptors reported by Janig et al. [2, 3].

In general, the pattern of effects on various MRs from phasic pressure and that from squeezing were similar. The effects of squeezing on MRs was stronger than those of phasic pressure. This fact suggests that more mechanical receptors were stimulated by squeezing, and afferent inputs from different types of receptors activated by squeezing had the same effect on each motoneuron.

The pattern of effects from radiant heating on various MRs was basically the same as that of mechanical stimulation. These results indicate that the effects of afferent inputs from the footpad produce hindlimb movements to decrease afferent inputs from the footpad. It could be considered that the physiological role of afferent input from footpads is to maintain stability of the hindfoot or escape from nociceptive stimulation.

REFERENCES