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Abstract

1. Effects of various kinds of adequate stimuli such as touching, pinching, heating and cooling to various skin areas as well as repetitive electrical stimulations to a nerve branch innervating the skin areas upon the unitary discharges of the expiratory or the inspiratory muscle units of the intercostal muscles were studied on the spinal dogs. Effects of pinching upon the intercostal nerve action potentials elicited in reflex by single electrical shock to the adjacent intercostal nerve were also studied. 2. Excitatory skin area for the expiratory discharges roughly exhibits a triangle, one of whose vertex faces the sternum, the side against the vertex corresponds to the apical line of the spine and includes the spot from where the discharges of a muscle unit are led off. The triangular area is surrounded by a belt-shaped zone having no reflex response. All the other wide area is the inhibitory one. 3. Both the excitatory and the inhibitory skin areas for the discharges of the inspiratory muscle unit are exceedingly narrow in contrast to those for the expiratory discharge, having a tendency to be limited to the small localized area involving the spot from where the discharges are led off. In the other extensive area, however, any reflex effect is not provoked. 4. The more intense and noxious the adequate stimuli become, the more prominent the effect come to be. 5. When the repetitive electrical stimuli to the skin nerve innervating the excitatory area are weak in intensity or low in frequency, an increasing discharge of the respiratory muscle unit results, whereas when the stimuli are sufficiently raised in either of the two factors above described, a remarkable inhibition preceded by a momentary acceleration ensues. In the case of stimulation of the skin nerve innervating the inhibitory area, however, the inhibition alone is obtained throughout. 6. Reflex action potentials in the intercostal nerve elicited by single shock stimuli to the adjacent intercostal nerve show a shortening of latency and an increase in size by pinching the excitatory skin area, while the reverse effects to those above described are obtained by pinching the inhibitory one.

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EXCITATORY AND INHIBITORY REFLEXOGENIC SKIN AREAS FOR THE INTERCOSTAL RESPIRATORY NEURONS IN THE DOG

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In the course of the previous studies^{5,6} on the mode of action of the intercostal muscles, a peculiar phenomenon was observed, namely, the train of volleys discharging coincidentally with respiratory rhythm decreased or sometimes increased in number provided when the skin of the animal was stimulated. Moreover, the aspect of the phenomenon above mentioned depended upon the acting muscle unit led off, skin area stimulated and the stimulating intensity applied. Present paper deals with the further details on the phenomenon.

METHODS

Eleven adult dogs whose spinal cord was transected at the level of about C₆ to C₇ under local anesthesia with 1 per cent solution of xylocaine were used. Though the animals thus prepared were sufficient to carry out the experiments, artificial respiration was resorted to throughout the experiments with the aim to keep the animals in as favorable conditions as possible. The animals were fastened in supine position, then the intercostal muscles were exposed from the second intercostal space to that of the seventh on one side.

In the experiments dealing with the muscle action potentials, unitary activities of the muscle were picked out by means of a needle electrode of concentric type whose inner needle was a silver wire of less than eighty micra in diameter. This was led to the in-put of a four stage R-C coupled amplifier and then connected to two sets of oscillograph, one of which was electromagnetic, another cathode ray in type. The former was used for the continuous recording of the action potentials, the latter for the observation of them.

Adequate skin stimulations were applied, i. e. bending the hair against the grain, pinching by a small forceps with sharpened tip, nipping

between thumb and fingers and heating or cooling by placing a small cotton ball moistened with water at various temperature between 0°C to 80°C.

Subsequently, a thin branch of skin nerve innervating the lower region of the abdominal wall or the region just dorsal to the spot from where the muscle action potentials were leading off was electrically stimulated with square pulse of various intensities and of frequencies.

In the experiments dealing with nerve action potentials, the recording was performed by a platinum bipolar electrode on which the central cut-end of 5th or 6th intercostal nerve being placed. The potential was provoked in reflex by single shock stimuli to a nerve branch coming from the rectus abdominus muscle or from the 7th intercostal nerve ipsilaterally. Thus the effects of pinching to various skin areas upon the nerve action potentials above mentioned were examined. The potentials in this series were observed and photographed by means of a cathode ray oscillograph simultaneously.

Care was taken not to deteriorate the excitability of the muscles and the nerves exposed by maintaining the room temperature constant at 28°C to 30°C and frequent pouring of liquid paraffin over the whole surface of the tissues.

RESULTS

On the reflex excitatory and inhibitory skin areas for the intercostal muscle activity.

The spike discharge of the intercostal muscles altering in number in concert with passive movements of the thorax which resulted from the artificial respiration, already proved to originate from the proprioceptive reflex⁶, promptly decreased or increased when a localized skin region of the body was slightly pinched. Moreover, the aspect of these effects differed from one another according to the muscle unit being recorded and the skin region being stimulated. The effects could be totally eliminated when the nerve branch innervating the skin region pinched was severed or 1 per cent solution of xylocaine was locally injected. Therefore, it can be deduced that the effects are attributable to a reflex in origin.

A) Effects of pinching upon the spike discharge of the expiratory intercostal muscle unit.

As shown in Fig. 1, for instance, the discharge of spike potentials picked out from an expiratory muscle unit at the 6th intercostal space in the right side (the position is marked by a circlet) remarkably decreases in number (A, B) when a skin spot situated at just contrary to the circlet

on the left side (a) or that on the abdominal wall (b) is respectively pinched. By pinching the spot localized just dorsal to the circlet (c), however, the discharge of same muscle unit increases in number (C).

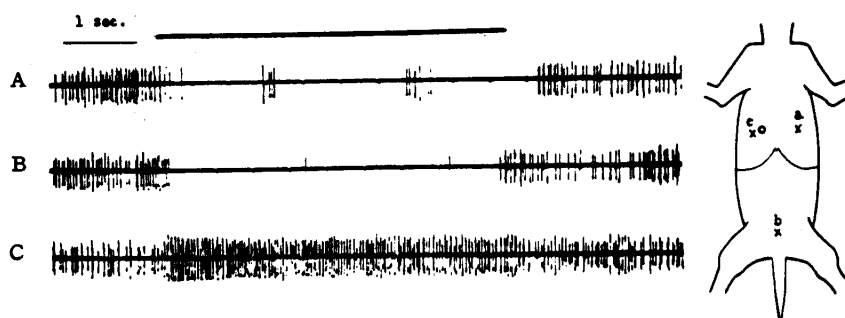


Fig. 1. Excitatory and inhibitory effects of pinching the various skin areas upon the discharges of the expiratory muscle unit in the spinal dog.

Electromyograms were led from a unit of the internal intercostal muscle in the 6th intercostal space on the right side. In the additional schema, a circlet roughly indicates the spot from where the discharges were led off, and the black crosses a, b and c indicate the spot being pinched. The record A, B and C was obtained by pinching a, b and c respectively. Straight line symbolizes the duration of pinching.

The effects obtained by pinching at many spots in various skin areas of the body, tail and hind limbs could be differentiated and summarized just as shown in Fig. 2, which displays a peculiar aspect consisted of excitatory signs (+) and with inhibitory ones (-). The excitatory skin area thus mapped is involved roughly in the following limits; a triangle, one of whose vertex is situated at the spot a few centimeters mediad to that from where the muscle action potentials are led off and the side against the vertex corresponds to the apical line of the spine, and the other sides, rostral border of the excitatory skin area and the caudal one respectively runs dorsad from the vertex above described along the 5th rib throughout and along the 8th costal cartilage in the medial portion then straight until it crosses the apical line of the spine at about L_2 vertebra.

When the muscle action potentials were led off from a spot situated more rostrally than that above described, for instance, from that in the 2nd intercostal space the excitatory skin area only shifts rostrad by the difference of intercostal space, but exhibits scarcely any change in shape (Fig. 2B).

The skin area giving rise to the inhibitory response extends over a

fairly wide region including the left thorax (contralaterally to the lead off spot), abdominal wall, tail and hind limbs.

The boundary between the two skin areas is not strict but presents a belt-shaped zone about a few centimeters in breadth, just as it surrounds the excitatory one. In the region, any kind of response can not be elicited.

Within the inhibitory skin area above described there can be noted some differences in the response intensity according to the spot pinched; namely, when compared with the response elicited from the thorax to that from the abdominal wall, it was found that the former is more prominent, besides, the one elicited from the lower abdominal region would be most marked (Fig. 3).

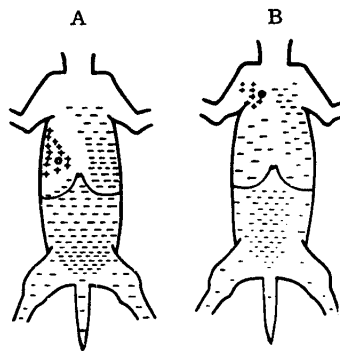


Fig. 2. Diagrams showing the extent of the excitatory (+) and the inhibitory (-) skin area for the discharges detected from an expiratory muscle unit of the internal intercostal muscle in the 6th intercostal space (A) and that obtained from another expiratory muscle unit in the 2nd intercostal space (B).

A circlet in both diagrams indicates the spot from where the discharges were led off. The strength of the effect is approximately indicated by the density of the signs.

B) Effects of pinching upon the spike discharge of the inspiratory intercostal muscle unit.

As illustrated in Fig. 4, inspiratory discharge led off from a muscle unit of intercartilaginous muscle in the 2nd intercostal space on the right side increased or decreased in number provided that the skin spot located near by the lead-off point which is indicated by a circlet in the additional diagram, or the spot symmetrically located on the left side was respectively pinched.

By pinching the spot in the other skin areas, however, none of responses could be elicited.

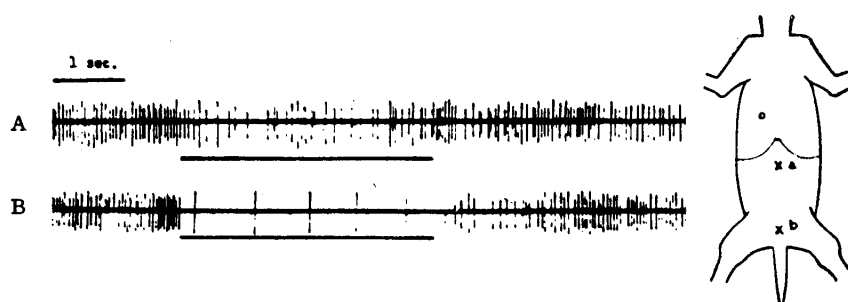


Fig. 3. Differences in the response intensity according to different spots pinched in the inhibitory skin area.

Electromyograms were led off from an expiratory muscle unit of the internal intercostal muscle in the 6th intercostal space on the right side. Pinching the spots a and b gave rise to the inhibition of the discharge as shown in A and B respectively. The strength of the response in B, however, is more prominent than that in A.

The skin area without response, as illustrated in Fig. 5 A, is remarkably extensive. This would be the characteristic trait which enables to discriminate the response skin area in the inspiratory unit from that obtained in the expiratory muscle unit. In the inspiratory muscle unit, moreover, there proved to be a few units having extremely localized excitatory skin area or those without (Fig. 5 B and C). And the presence of such varieties in the response area between units would be another characteristic trait.

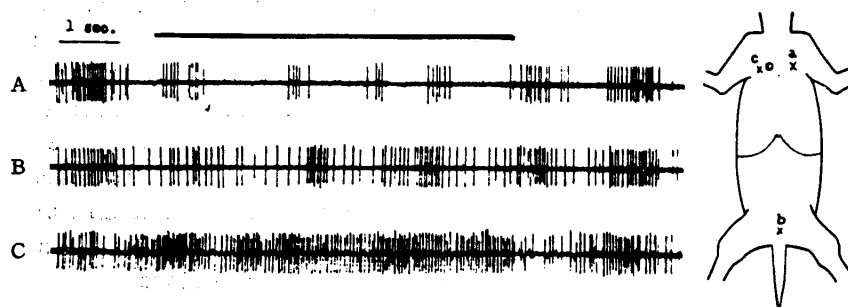


Fig. 4. Effects of pinching the various skin areas upon the discharges of an inspiratory muscle unit.

Electromyograms were led off from the intercartilaginous muscle in the 2nd intercostal space on the right side. The site is roughly indicated by a circlet in the additional diagram. The discharges were inhibited (A), unchanged (B) and accelerated (C) when the skin spots a, b and c were respectively pinched.

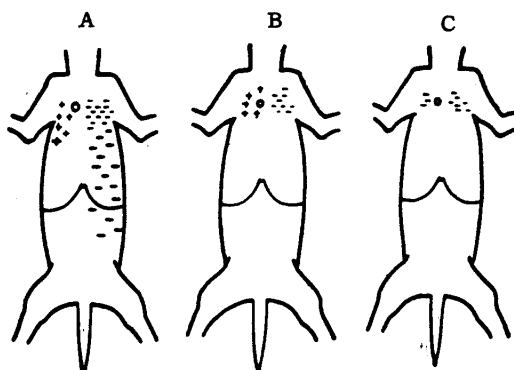


Fig. 5. Diagrams showing the extent of the excitatory (+) and the inhibitory (-) skin areas for the discharges of three different inspiratory muscle units led off from the intercartilaginous muscle in the 2nd intercostal space on the right side (○).

The presence of individual differences between the response aspect of skin area should be noted.

Relations between the reflex response and the adequate skin stimuli.

In a series of experiments to determine the reflexogenic skin areas as described in the preceding chapter, pinching was the only stimulus used throughout. But whenever a light touch was applied to the skin, reflex responses, i. e. an increase or decrease of spike discharge of the individual intercostal muscle fibers ensued without fail, however, the responses thus ensued were generally less prominent in appearance as compared with those elicited by pinching.

In the case of thermal stimuli, responses, the inhibitory as well as the excitatory, could be elicited only when the temperature was over about 45°C or under about 10°C at least. And the more the thermal degree raised or lowered the more intensive the aspect of both responses become. When the degree of thermal stimuli applied was within a certain limit, closing about the body temperature, no recognizable response could be obtained. The typical responses of an expiratory muscle unit by stimulation to both the excitatory and the inhibitory skin areas with warm water (Fig. 6), as well as with cold water (Fig. 7) are illustrated.

On the peculiarities of the reflex responses to repetitive electrical stimulations of nerve branch innervating the excitatory or inhibitory skin areas.

A certain muscle unit which responds to pinching and reveals specific reflexogenic skin areas may also responds to repetitive stimulations of a nerve coming from each skin area. But the response was quite different

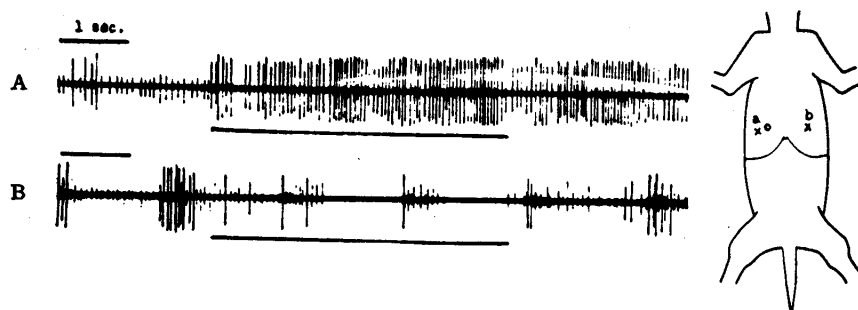


Fig. 6. Effects of heating the excitatory and inhibitory skin areas upon the discharges of an expiratory muscle unit.

Electromyograms were led from the internal intercostal muscle in the 7th intercostal space on the right side. The spot is indicated by a circlet in the additional diagram. A small cotton ball moistened with water heated to 50°C was placed on the spots whose sites are indicated by a and b. Each record A (excitation) or B (inhibition) is followed by stimulation of a or b. The straight line shows the duration of heating.

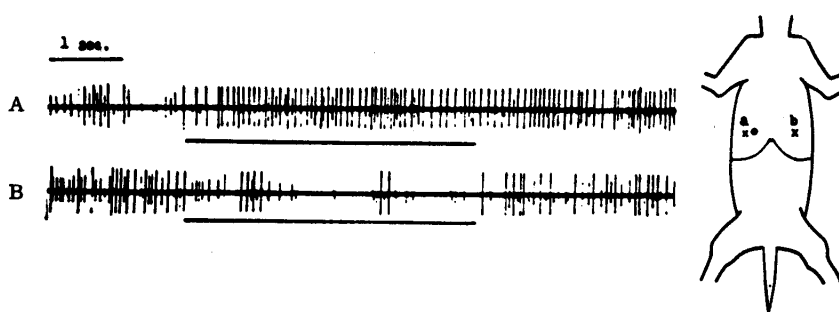


Fig. 7. Effects of cooling the excitatory and inhibitory skin areas upon the discharge of an expiratory muscle unit.

A small cotton ball moistened with water cooled to about 0°C was placed on the skin (a, b). Other explanations are the same as those in Fig. 6.

in aspect from each other whether the nerve stimulated was coming from the excitatory skin area or that from the inhibitory one.

Fig. 8 exemplifies the response to stimulation of a nerve from the excitatory area. It can be noted in this figure that when the intensity of stimuli (frequency was kept at 50/sec throughout in this case) was increased just above 3 volts, impulses of each volley increased in number. And at the intensity of about 6 volts the impulses not only increased in each volley but continuously appeared even in the intervals between these volleys. But with a further increase in the intensity, however, the prominent excitatory response above described gradually becomes faint, then

converted into the inhibitory response. The lowest record of the figure in which the intensity applied was at 20 volts shows a marked enduring inhibition preceded by a momentary out-break of one or two impulses.

In case stimuli with various frequencies instead of those with various intensities were applied, the aspect of responses was similar to that exemplified in Fig. 8; therefore, the changing of the stimuli in intensity bears probably a similar relation to that in frequency.

Briefly stated, when a nerve branch innervating the excitatory skin area for a certain intercostal muscle unit was electrically stimulated, the presence of lower as well as higher limits in both intensity and frequency of the stimuli for provoking an exclusive excitatory response can be substantiated.

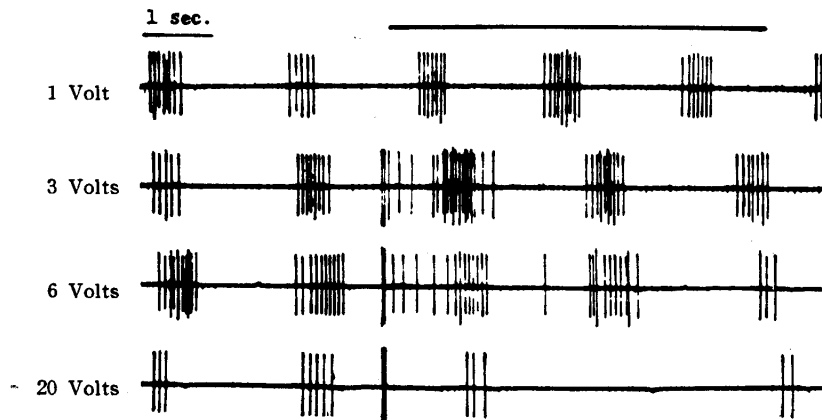


Fig. 8. Responses of an expiratory muscle unit to repetitive electrical stimulation of a nerve branch innervating the excitatory skin area with different intensities at constant frequency of 50/sec.

Sole excitation at 3 volts to 6 volts and complete inhibition preceded by a short initial impulses at 20 volts successively occurred in the same muscle unit. Straight line indicates the duration of stimulation.

Whenever the intensity or the frequency exceeds the threshold, repetitive electrical stimulations to a nerve innervating the inhibitory skin area can elicit the inhibitory response. And with a further increase in the intensity or in the frequency any change in the response aspect, such a reversal as shown in Fig. 8, can never be attained (Fig. 9). In addition, it is generally conceived that the threshold in these cases may scarcely be lower than that in the case of excitation.

From the results above described, difference between the inhibitory response ensued by stimulation of an excitatory skin nerve with suffi-

ciently high intensity or frequency and those ensued by stimulation of an inhibitory skin nerve can be said that the former has a short initial discharge of a few impulses whereas the latter none.

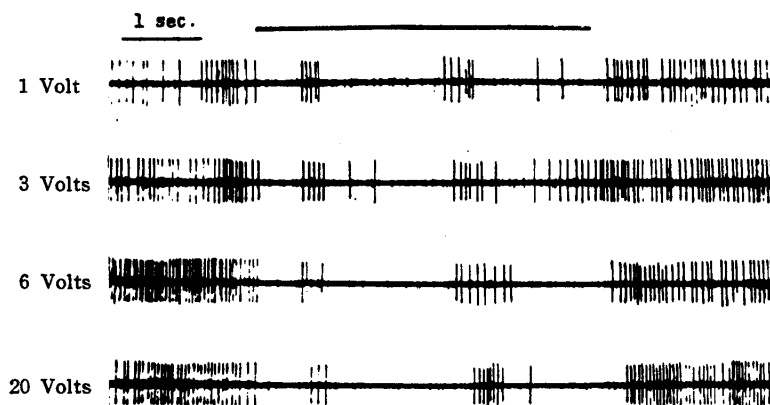


Fig. 9. Responses of an expiratory muscle unit to repetitive electrical stimulations of a nerve branch innervating the inhibitory skin area with different intensities at constant frequency of 50/sec.

Whenever a response is elicited, it is solely an inhibitory one. Any particular relation between the response aspect and the intensity or frequency of stimuli applied is not observed. Explanations for others are the same as before.

On the detailed features of the excitatory and inhibitory responses.

When a branch of intercostal nerve innervating the abdominal rectus muscle was stimulated by single shock stimuli at regular intervals there occurred reflex action potentials in the intercostal nerve presented just rostral or caudal to that stimulated ipsilaterally. The potentials thus evoked were also influenced by the skin pinching.

Action potentials of small size and long latency being provoked by shock stimuli of just above the threshold produced a characteristic increase in size and shortening of latency when a skin spot in the excitatory area was pinched (Fig. 10 A). And even the stimuli were subliminal in intensity can easily produce a distinct reflex action potentials during the pinching. But the latency maximally shortened always exceeded 5 msec., proving to have no monosynaptic connections in this reflex.

On the contrary, prominent action potentials being provoked by supramaximal shock stimuli showed inverse changes to that above described when a skin spot in the inhibitory area was similarly pinched (Fig. 10 B). Moreover, the degree of inhibition depends on the location

of the spot pinched in the inhibitory skin area, as shown in Fig. 11, for example, the response is depressed to about 55 per cent in size and is prolonged to about 111 per cent in latency compared with the control value when the spot 'a', indicated in the additional diagram, is pinched (A), whereas it is completely abolished when 'b' is pinched (B).

Detailed aspect of these changes, can be evaluated clearly from Table 1.

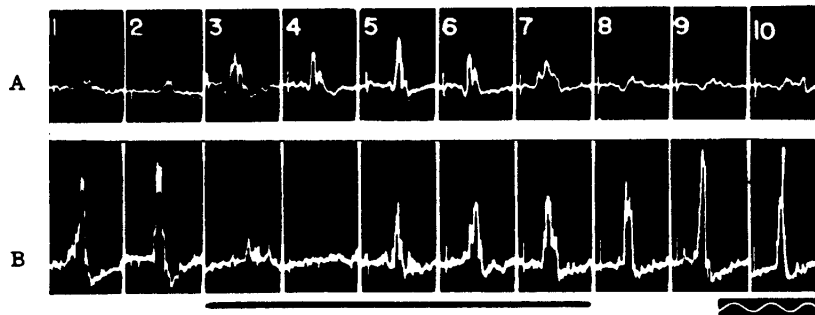


Fig. 10. Facilitation (A) and inhibition (B) of the reflex potential by pinching the spot in the excitatory and inhibitory skin areas respectively.

Reflex potentials were provoked by single shock stimuli to a nerve innervating the abdominal rectus muscle, ramifying from the 6th intercostal nerve, and were led off from the central cut-end of the 7th intercostal nerve on the right side. Intervals between numbered traces are equally 2 sec to each other. Straight line indicates the duration of pinching. Sweep speed of all traces can be calculated from the signal showing 60 cycles per sec.

Table 1. The change of latency and the size of reflex action potentials by pinching the skin areas expressed as percentage of control values (values before pinching).

Each value is an average calculated from several records under respective condition.

		Before pinch	During pinch	After pinch
Excitatory skin area	Latency	100	73	97
	Size	100	328	70
Inhibitory skin area	Latency	100	177	98
	Size	100	38	112

These results can verify that the excitatory and inhibitory effect of skin pinching upon the proprioceptive reflex of intercostal motoneurons are consequently interpreted as the changes of two factors; i. e. synaptic transmission and the threshold.

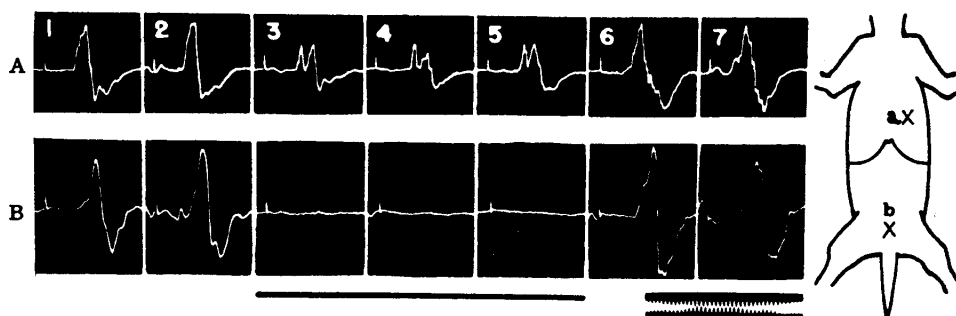


Fig. 11 Different grades of inhibition of reflex action potential by pinching the skin at different locations.

Nerve stimulation and potential recording were carried out on the right side. A : When a skin spot in the left thorax was pinched, ensuing inhibition was conspicuous but not complete. B : Pinching a spot in the lower region of the abdominal wall elicited a complete inhibition. Sweep speed signal indicates 500 cycles per sec. Other explanations are the same as those in the preceding

DISCUSSION

Sherrington⁷ stated that on occasions there occurs an exceptional extension, instead of usual flexion of a limb provided that the skin or cutaneous nerve of the same limb is stimulated.

By using the monosynaptic method of recording, Hagbarth^{2,3} studied on the occurrence of the phenomenon above described, and concluded that these exceptions are attributed to where about cutaneous regions would be stimulated. According to his paper it was reported that whichever the muscle of a hind limb it might be, flexors or extensors, reflex excitation or inhibition of the muscle can result when the afferent impulses from a skin area covering the muscle or from that excluding the former area are driven into the spinal cord respectively.

The results on the expiratory intercostal muscle unit above described seem to obey the rule proposed by him, however, those on the inspiratory do not. There is scarcely kind of skin stimulus but gives reflex influence upon intercostal motoneurons and, moreover, the more the stimuli become noxious the more extreme the influence come to be; and these facts are just identical with those reported in his paper.

Excitatory response by repetitive electrical stimulation of the skin nerve innervating the excitatory area, as illustrated in Fig. 8, reversed back to itself into the inhibitory one when the intensity or the frequency of the stimuli was sufficiently raised. It may be assumed that why the

inhibition does not produce by stimulation of the excitatory skin area can probably be attributed to an insufficient elicitation of the afferent impulses in quantity. Similar reversing phenomenon has been observed frequently on the respiratory reflexes⁴. Quite recently, *Frank* and *Fuortes*¹ have found out the presence of a kind of spinal interneurons displaying such a reversal. These findings will contribute in enabling the elucidation of the reversing phenomenon analogically. But in the animals not spinalized the reflex changes above described were markedly modulated. This leads us to a question: How about the role of the higher centers concerned? The question, however, should have to be solved in the future studies.

SUMMARY

1. Effects of various kinds of adequate stimuli such as touching, pinching, heating and cooling to various skin areas as well as repetitive electrical stimulations to a nerve branch innervating the skin areas upon the unitary discharges of the expiratory or the inspiratory muscle units of the intercostal muscles were studied on the spinal dogs. Effects of pinching upon the intercostal nerve action potentials elicited in reflex by single electrical shock to the adjacent intercostal nerve were also studied.

2. Excitatory skin area for the expiratory discharges roughly exhibits a triangle, one of whose vertex faces the sternum, the side against the vertex corresponds to the apical line of the spine and includes the spot from where the discharges of a muscle unit are led off. The triangular area is surrounded by a belt-shaped zone having no reflex response. All the other wide area is the inhibitory one.

3. Both the excitatory and the inhibitory skin areas for the discharges of the inspiratory muscle unit are exceedingly narrow in contrast to those for the expiratory discharge, having a tendency to be limited to the small localized area involving the spot from where the discharges are led off. In the other extensive area, however, any reflex effect is not provoked.

4. The more intense and noxious the adequate stimuli become, the more prominent the effect come to be.

5. When the repetitive electrical stimuli to the skin nerve innervating the excitatory area are weak in intensity or low in frequency, an increasing discharge of the respiratory muscle unit results, whereas when the stimuli are sufficiently raised in either of the two factors above described, a remarkable inhibition preceded by a momentary acceleration ensues. In the case of stimulation of the skin nerve innervating the in-

hibitory area, however, the inhibition alone is obtained throughout.

6. Reflex action potentials in the intercostal nerve elicited by single shock stimuli to the adjacent intercostal nerve show a shortening of latency and an increase in size by pinching the excitatory skin area, while the reverse effects to those above described are obtained by pinching the inhibitory one.

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