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# On the Behavior of the Respiratory Muscles During Vomiting\*

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## Abstract

In order to produce vomiting in the dogs decerebrated and unanesthetized, apomorphine or copper sulfate was administered. The behaviors of both the inspiratory and the expiratory muscles were studied through the course of the act of vomiting by the electromyographic technique. The results are summarized as follows: (1) The most significant signs of vomiting seems to be the recurrent vomiting volleys from the vomiting center each of which is produced abruptly and transiently. (2) The peculiarities of the vomiting volley consist in the simultaneous discharges of both the inspiratory and the expiratory muscles, resulting in the so-called retching movement. (3) The vomiting volleys, in their rhythm, seem to arise independent of the respiratory center, but the former are capable of affecting the respiratory centers at any respiratory phase. (4) The acceleration of the breathings observed prior to the retching seems to be due to the invigorated activity of the respiratory centers affected directly by the administration of the vomiting agents without an intermediate step by the vomiting centers. (5) The simultaneous contraction of the diaphragm and the abdominal muscles are merely a component of a peculiar type of the respiratory movements, namely, that of the retching. (6) The glottis muscles are, however, ruled out from the principle described in (2): the closer of the glottis muscles contracts during the retching, while the opener is completely inhibited.

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## ON THE BEHAVIOR OF THE RESPIRATORY MUSCLES DURING VOMITING

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Surveying the history of the studies on vomiting, some authors<sup>4,9,10,13</sup> consider that the active contraction of the stomach plays a major rôle in the expulsion of the vomitus, while many others<sup>2,3,5,6,7,11,12,13,14,15,16</sup> call attention especially to the importance of an increase in the abdominal pressure caused by the forceful contractions of the diaphragm and the abdominal muscles upon the emesis.

The changes of the respiration during vomiting were studied minutely by GOLD and HATCHER<sup>5</sup>. In their experiments the respiratory movements were recorded by covering the nose and mouth of the animal (cats and dogs) with a flask and the results of their experiments are summarized as follows: the glottis closes at the end of expiration or at the very beginning of inspiration, with the diaphragm high up, before the first retching movement in normal vomiting. Retching consists of a series of spasmodic abortive respiratory movements with the glottis closed, during which an inspiratory effort of the chest muscles and diaphragm occurs simultaneously with spasmodic contraction of the abdominal muscles. By their experimental methods, however, it is not sufficiently clear about the relative time when and the mutual mode how the diaphragm, the abdominal muscles and the other respiratory muscles contract during the retching movement.

As to the techniques employed by more recent authors<sup>14,15</sup>, the same argument can be true. BORISON and WANG<sup>1</sup> who studied the central vomiting mechanism made a relevant remark that it is quite difficult to record graphically the movements which are unmistakably indicative of vomiting. The drawback may possibly be overcome by means of an electromyographic technique. From these points of view, we have attempted to trace more exactly, by the electromyographic technique, the behavior of the activity of the respiratory muscles during the act of vomiting.

### METHOD

The experiments were performed mostly in dogs and occasionally in

rabbits. An alternating current, which was of 50 volts and 60 cycles per second, was passed through the electrodes attached to the frontoparietal regions of the skull of the unanesthetized animal for 5 to 6 seconds to produce the state of the shock lasting for about 20 minutes. The animals were then decerebrated by means of the technique reported previously<sup>8</sup>.

The action potentials were led off simultaneously from various inspiratory and expiratory muscles and the mutual temporal relationships existing between the activities of these muscles were investigated. The electrode employed was made up of a glasscapillary with an outer diameter of 10 to 20 micra into which a silver wire reduced electrolytically to about 5 micra in diameter at its tip was inserted. This electrode was of 2 to 3 cm. in length and was connected with the grid of an amplifier by means of a silver wire of 50 micra in diameter and of 15 to 20 cm. in length. These arrangements render the tip of the electrode possible of maintaining the same position throughout the vomiting despite the accompanying movements of the body.

The amplifier used was of the five stage, resistance-capacity coupled, and the overall time constant was 0.25 second. The electromyogram and the pneumogram were simultaneously recorded. The pneumograph attached to the thorax was connected by a thick rubber tube with a Marey's tambour provided with a small mirror. For the purpose of inducing vomiting, in some cases apomorphine of 2 to 4 mg. per kilogram body weight was administered intravenously, and in other cases a saturated solution of copper sulfate was introduced into the stomach using catheter.

## RESULTS

1. The behavior of the respiratory muscles of dogs during the act of vomiting.

Soon after the introduction of 100 to 300 c. c. of a saturated solution of copper sulfate the breathing increases rapidly in the frequency and depth (stage of nausea) until it culminates, within one minute or so, to the spasmodic movement lasting for a quite long time (stage of retching). By this retching movement the gastric contents (copper sulfate and food mass) are explosively thrown out with the mouth wideopen. In some instances, such a drastic movement occurs repeatedly at a short interval.

In the cases in which an apomorphine is administered, the changes of the breathings are essentially the same as those seen in the cases administered with copper sulfate. The behavior of both diaphragm and m. rectus abdominis before and during the act of vomiting is illustrated in Figure 1. In quiet breathings the ventral slip of the diaphragm discharges during

the inspiratory phase, while *m. rectus abdominis* does not, even though the deflections of the cardiac origin are to be seen, as shown in Fig. 1A. One minute after the i. v. administration of apomorphine of 2 mg. per kilogram body weight, the breathings quicken markedly as shown in Fig. 1B. At this stage the discharges of the inspiratory muscles are remarkably accelerated and the discharges of *m. rectus abdominis* also appear continually, although they are of a low frequency and do not break into a burst. However, 30 seconds later, the stage of retching is attained and the breathings of a peculiar type occur successively 4 to 25 times with the interval of 1—1.5 seconds. This type of the breathing which might be

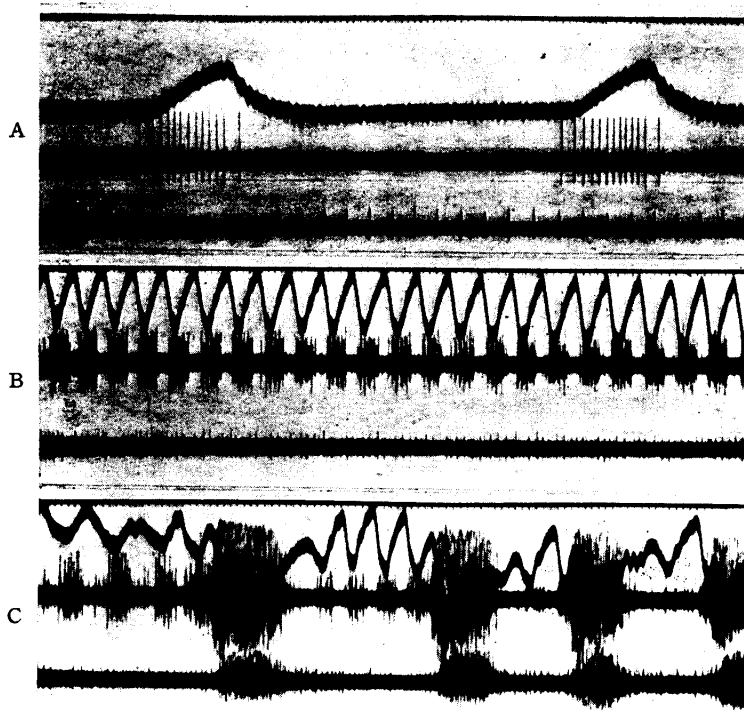


Fig. 1. Action potentials led off from diaphragm and *m. rectus abdominis* during vomiting.

Upper curve: movements of the thorax, inspiration upward.

Middle curve: spike discharges of the diaphragm.

Lower curve: spike discharges of *m. rectus abdominis*. Time intervals, 1/12 second.

A. normal breathings (before administration of apomorphine)

B. breathings before vomiting (30 seconds after administration)

C. breathings during vomiting. Note simultaneous discharges of diaphragm and *m. rectus abdominis*.

called "retching" is characterized by the abrupt and simultaneous activities of both diaphragm and m. rectus abdominis. The activities continue for only about one second till they cease again abruptly, but they are so vigorous that the gastric contents are thrown up into the mouth. The close observation of the electromyogram reveals that the activities of the muscles can occur at any phase of the breathing and in the figure illustrated they begin at the various points of the inspiratory phase.

In some cases and especially when the copper sulfate is administered, there can also be occasionally seen such a long persistent discharge as that illustrated in the following Fig. 2. A similar phenomenon to that mentioned above is also observed on another part of inspiratory and expiratory muscles chosen arbitrarily, for example, m. intercartilagineus and m. transversus thoracis or m. intercostalis externus et internus. One example of a large number of experiments is illustrated in Fig. 2. In this example the action potentials are led off from both m. intercartilagineus and m. transversus thoracis. Before introducing the vomiting agent into the stomach, these inspiratory and expiratory muscles act alternately and the

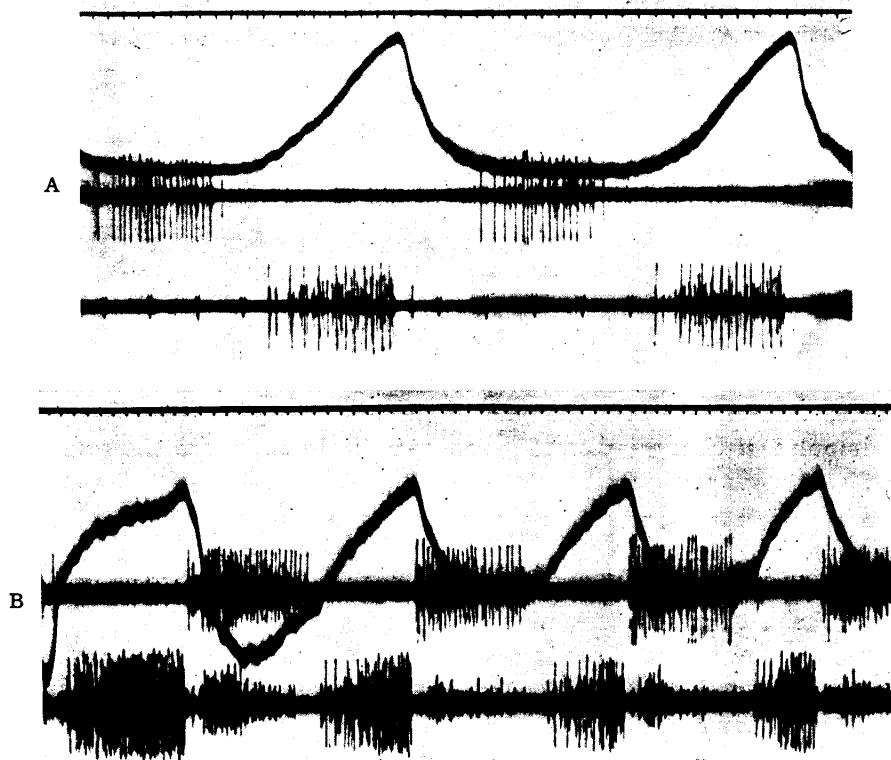




Fig. 2. Action potentials led off from the inspiratory and expiratory muscles during the act of vomiting.

Upper curve: movements of the thorax, inspiration upward.

Middle curve: spike potentials of *m. transversus thoracis* (expiratory).

Lower curve: spike potentials of *m. intercartilagineus* (inspiratory). Time intervals of 1/12 second.

A: normal breathings (before introducing copper sulfate).

B: breathings just before vomiting (30 seconds after introduction)

C: breathings during vomiting. Note continuous and simultaneous discharges of the inspiratory and expiratory muscles.

former during the inspiratory phase, while the latter during the expiratory phase (Fig. 2A). About one minute after the administration of the agent the breathings quicken remarkably; namely, the spike potentials of the muscles showing an increase of their impulse frequencies in individual units, and with additional units (Fig. 2B).

It is to be noted that *m. intercartilagineus* acts not only during the inspiratory phase but also during the expiratory phase, although much more weakly during the latter phase. This stage is followed by that of the retching illustrated in Fig. 2C: as soon as one cycle of the inspiration comes to an end, the simultaneous discharges of both inspiratory and expiratory muscles occur and continue for five to six seconds, increasing rapidly the impulse frequencies of individual units as well as the number of active units and the activities of these muscles becoming then abruptly weaker, while the level of the pneumogram returning to the normal and the impulse discharges recurring again similarly as before the retching. Such a vigorous retching is in general followed several times by retchings of about the same vigor, in some of which the discharges of the inspiratory and expiratory muscles wane and wax synchronously. The pneumogram shows that the thorax is, in most cases, held in the expiratory position during the retching, in other words, the activity of the expiratory muscles predominate over that of the inspiratory; but occasionally the reverse is also the case.

The behavior of the activity of the opener as well as the closer of the glottis during the act of vomiting has been studied. In the electromyo-

gram simultaneously led off from the opener of the glottis, *m. cricoarythenoideus dorsalis*, and from its closer, *m. cricoarythenoideus lateralis*, the alternate activity of the muscles can be observed; the activity of the former occurs during the inspiratory phase, while that of the latter during the expiratory phase (Fig. 3A). From the result it may be said that *m. cricoarythenoideus dorsalis* as well as *m. cricoarythenoideus lateralis* fall respectively, in broader sense, under the category of the inspiratory as well as of the expiratory muscles.

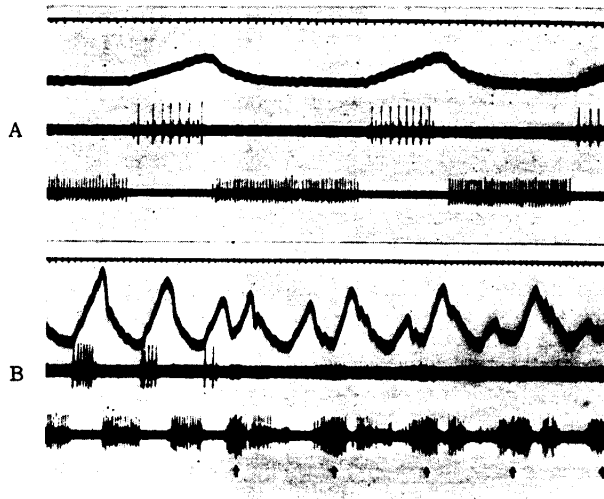


Fig. 3. Action potentials led off from the muscles of the glottis during the act of vomiting.

Upper curve: the movements of the thorax, inspiration upward.

Middle curve: spike discharges of *m. cricoarythenoideus dorsalis* acting as the opener of the glottis.

Lower curve: spike discharges of *m. cricoarythenoideus lateralis* acting as a closer of the glottis. Time intervals, 1/12 second.

A: normal breathings. B: breathings during vomiting.

With the administration of apomorphine, the activities of the opener and closer are accelerated and are coordinated with other respiratory muscles. When the retching movements occur recurrently, the closer of the glottis discharges abruptly and vigorously corresponding to each retching, as shown by arrows in Figure 3B, normal discharge being interpolated between each retching discharge, while the opener ceases to discharge through the whole course of the attack. The results run contrary to our expectation of the muscles of the glottis to contract simultaneously during the retching, and at the present we are unable to explain the mechanism of inhibition just described. Another closer of the glottis, *m.*



cricothyreoideus likewise has a similar activity to that of *m. cricoarythnoideus lateralis*.

## 2. Effects of apomorphine upon the respiratory muscles of rabbits.

It has been stated by MILLER<sup>12</sup> that in rabbits vomiting does not occur. According to electromyograms led off from the ventral slip of diaphragm and the abdominal muscles, in quiet breathings the former acts during the inspiratory phase, while the latter does not act at all. With the *i. v.* administration of apomorphine of 2 to 5 mg. per kilogram body weight, the breathings are remarkably accelerated. We are not, however, able to lead any spikes from the abdominal muscles and to find any sign of retching or of vomiting throughout the experiment. From this result, it may be said that in rabbits the existence of the vomiting centers is doubtful.

## DISCUSSION

That the diaphragm and the abdominal muscles contract simultaneously during the retching has already been repeatedly observed by other authors<sup>5,14,15</sup>, but the direct recording of the contraction of the muscles has never been attempted so far. The pneumographic techniques in common use are not quite so adequate as to reveal the behaviors of the individual muscles, while the electromyographic technique is, in this respect, a very useful device, which is amply demonstrated as such through the course of our experiments.

As regards the phase at which the retching occurs, our results are somewhat divergent from those of other authors: according to GUINARD<sup>6</sup> and PAILLARD<sup>14</sup>, the retching occurred at the beginning of the inspiration, and to GOLD and HATCHER<sup>5</sup>, it occurred at the end of the expiration or at the very beginning of the inspiration, while in the opinion of BORISON and WANG<sup>1</sup>, it occurred at the peak of the inspiration. Our results show that the retching can occur at any phase of the respiration and not so rarely even in the expiratory phase. This seems to be due to the circumstances that the volleys discharged from the vomiting centers are, in their rhythm, independent of those produced from the respiratory centers. We believe that the discrepancies found among the opinions of other authors may be settled on the basis of our results and consideration presented in this paper.

A criterion of the activity of the vomiting centers is the successive occurrence of the retching movements. The peculiarities of the retching consist in that both the inspiratory and the expiratory muscles contract simultaneously and forcibly, although alternately in quiet breathings. It

must be emphasized that the simultaneous contractions of the diaphragm and the abdominal muscles are merely a component of the peculiar respiratory movements, namely, that of the retching movements. There is an exception, however, to be observed in the glottis muscles, i. e. the closer contracting during the retching, while the opener being completely inhibited. BORISON and WANG<sup>17</sup> attempted to explore the action potentials from the regions where the vomiting centers are localized, but they failed to obtain any conclusive finding being interfered by the accompanying movements of the animal body occurring invariably during the retching.

The acceleration of the breathings observed prior to the retchings appears to be due in large measure to the invigorated activity of the respiratory centers affected directly by the administration of the vomiting agents without any intermediate step by the vomiting centers. Such a view may be endorsed by the fact that the breathing in rabbits administered with apomorphine are remarkably accelerated without producing the retching movement.

#### SUMMARY

In order to produce vomiting in the dogs decerebrated and unanesthetized, apomorphine or copper sulfate was administered. The behaviors of both the inspiratory and the expiratory muscles were studied through the course of the act of vomiting by the electromyographic technique. The results are summarized as follows :

- (1) The most significant signs of vomiting seems to be the recurrent vomiting volleys from the vomiting center each of which is produced abruptly and transiently.
- (2) The peculiarities of the vomiting volley consist in the simultaneous discharges of both the inspiratory and the expiratory muscles, resulting in the so-called retching movement.
- (3) The vomiting volleys, in their rhythm, seem to arise independent of the respiratory center, but the former are capable of affecting the respiratory centers at any respiratory phase.
- (4) The acceleration of the breathings observed prior to the retching seems to be due to the invigorated activity of the respiratory centers affected directly by the administration of the vomiting agents without an intermediate step by the vomiting centers.
- (5) The simultaneous contraction of the diaphragm and the abdominal muscles are merely a component of a peculiar type of the respiratory movements, namely, that of the retching.
- (6) The glottis muscles are, however, ruled out from the principle

described in (2): the closer of the glottis muscles contracts during the retching, while the opener is completely inhibited.

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