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NORMAL RESPIRATION AND THE INFLUENCE OF THE VAGI.

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Normal respiration consists of inspiration and expiration without any pause, whether the respirations are slow or fast. In man the ratio of inspiration to expiration is approximately 3 : 4, but with individual variations. As is well known the rate varies considerably in different individuals, the variations being much greater than those of the pulse. The average rate in a normal man may be given at about sixteen a minute, but it is as high as twenty-four and as low as four. There are usually five to eight heart beats to each respiration. A tracing which has been reproduced in many text-books showing more than twenty heart beats to each respiration is obviously abnormal.

A slow pulse is not necessarily accompanied by slow respirations. Thus, in Fig. 1, from a man of 44, the pulse is 70 per minute, the respirations 9; in Fig. 2, from a lad of 16, the pulse is 44, the respirations 14; in Fig. 3, from a man of 36, the pulse is 68, the respirations 5.

Fig. 4 is from a dog, showing simultaneous tracings of respiration (*r.*), of aortic blood pressure (*ao.*), and of pulmonary blood-pressure (*p.*). There are five heart beats to each respiration. It will be noticed that, as in man, there is no pause between expiration and inspiration. This is true also of other animals. Under conditions in which the respiratory centre is depressed a definite pause may become apparent. Such conditions can be produced by drugs, especially anæsthetics in excess, as well as by failure in the supply of oxygenated blood to the centre, as may be caused by a severe operation, especially if attended by hæmorrhage[1].

The essential stimulus to inspiration which is constantly in operation is chemical and is afforded by the CO_2 tension of the blood circulating in the bulb [Haldane]. The inspiration is cut short as soon as the pulmonary alveoli become distended. The distension mechanically excites the endings of afferent fibres of the vagus; these convey impulses to the centre, reducing its excitability so that it ceases to respond to the constant stimulus. This inhibition affects both the active contraction of the muscles of

[1] The Cheyne-Stokes phenomenon with its prolonged pauses affords a striking instance of the effect of failure of the supply of blood to the centre.

inspiration and their tonus[1]. As a result of this inhibition the elastic reaction of the lungs and of the thoracic walls causes the alveoli to become diminished in size and expiration results.

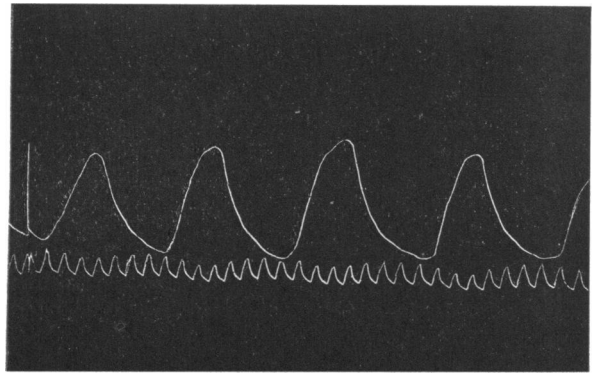

Fig. 1. From a man, aged 44. In this and the other cases from man, the respirations were recorded by Marey's pneumograph placed over the epigastrium, the pulse beats by a sphygmoscope connected with the arm-band of a Riva-Rocca.

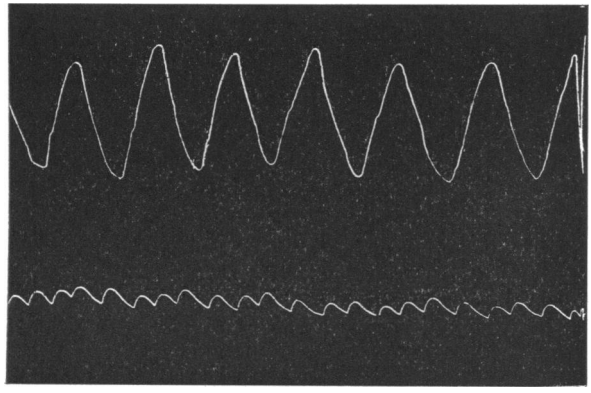

Fig. 2. From a lad, aged 16.

But expiration is not a purely passive phenomenon. It is always accompanied by some contraction of the muscles of expiration; this is better marked in quadrupeds than in man, but is never absent. What exactly is the cause of this contraction is uncertain. It was assumed by

W. R. Hess [1930], employing a mechanical method, has emphasised the effect of the condition of distension of the alveoli in modifying the tonus both of the diaphragm and of the thoracic muscles. Keller and Loeser [1930] have shown the constant presence of such tonus and have studied its variations in different conditions of inflation.

Hering and Breuer [1868] that the distension of the alveoli not only produces inhibition of inspiration but at the same time excites expiration. That afferent fibres of the pulmonary vagi can be stimulated by deflation

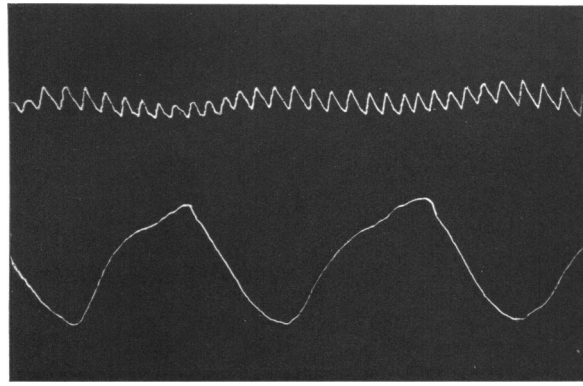

Fig. 3. From a man, aged 36. (In this figure the downstroke is inspiration, in all the others the upstroke.)

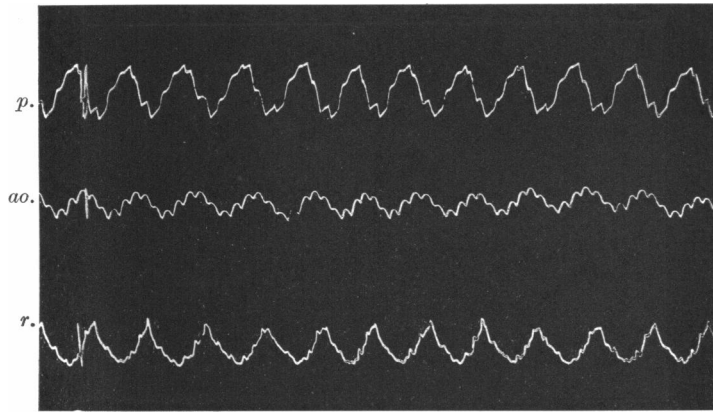

Fig. 4. From a dog, anæsthetized with chloralose. *r.* tracing of respirations; *p.* respiratory fluctuations of pulmonary blood-pressure; *ao.* respiratory fluctuations of aortic blood-pressure.

and that these act antagonistically to those excited by distension of the alveoli, increasing the excitability of the inspiratory centre to the continued stimulus of CO_2, is unquestionable, but it is still controversial whether they are called into play in quiet respiration.

According to Schenck [1903] this only occurs in forced expiration. Adrian [1926] found that oscillations of the capillary electrometer were at a minimum during expiration,

but Wachholder and McKinley [1929] noticed with every change of volume of the lungs increased oscillations of the string galvanometer, indicating an increase of strength of tonic impulses transmitted by the vagi.

The result of this alternation of excitation and inhibition constitutes the "Selbst-steuerung" of Hering and Breuer, who demonstrated it by the classic experiment of closing the trachea in the inspiratory and expiratory phases respectively.

All later investigators have confirmed their results, *e.g.* Gad [1879], Head [1889], Haldane and Mavrogordato [1916] (in man), and many more. The phenomena are strikingly exhibited by breathing into and out of a large reservoir of air maintained at a positive or a negative pressure some 20 cm. H_2O above or below the atmospheric pressure [Stefani and Sighicelli, 1888].

That there are two sets of afferent fibres in the vagi having antagonistic actions on respiration was first shown by Traube [1847] and generally recognized. Stimulating the central end of a cut vagus provokes either increased or diminished activity of respiration according to the character and intensity of the stimulation.

Since the rate and depth of respiration is usually profoundly affected by section of the vagi it is commonly assumed that respiration, so far as its rhythm is concerned, is regulated solely through those nerves. But there are reasons against this view. For the rhythmic succession of inspiration and expiration is continued after section of both vagi. True, it is generally at a slower rate, but, as Gad was the first to point out, this is not always the case. And if the obstructive dyspnœa which results from section of the laryngeal fibres is avoided, the slowing is never permanent, and, even when well marked at first, disappears after a time. As Christiansen and Haldane [1914] showed, any agency which obstructs the passage of air causes respiration to be slower and deeper. This is a constant feature of the obstruction caused by paralysis of the vocal cords—or even of one cord only. It can be avoided by cutting the vagi below the place where they give off the inferior laryngeals: if this is done no permanent slowing results [Boothby and Shamoff, 1915]. It can also be obviated by previous cauterization of the glottis [Sharpey-Schafer, 1919]. As was there shown and illustrated by numerous examples and tracings, in some animals section of both vagi may produce either no slowing, or such slowing as occurs is not permanent[1].

[1] The authors of a recent article in the *J. Physiol.* [Hammouda and Wilson, 1932] "on the function of the vagus in respiration" attribute to me the opinion that the slowing of respiration which usually immediately follows division of the vagi is caused by this dyspnœa. I have nowhere expressed such an opinion. The authors have either not read my paper carefully or have misunderstood my statements.

There must, therefore, be some regulating mechanism besides that described by Hering and Breuer. What this other mechanism is there can be no difficulty in deciding. For, as Fleisch [1928] has shown, the respiratory muscles are subject to the same conditions as to reciprocal innervation as the skeletal muscles, in which contraction reflexly provokes inhibition of their antagonists.

We may suppose that normally both vagal and muscular mechanisms are in operation, although in most cases the vagal mechanism predominates. In the absence of one mechanism the other may take on the regulating function alone. That the muscular mechanism can operate by itself was shown by A. D. Macdonald and myself (1925) in an experiment on a dog, which was brought to the notice of the Society a few years ago. In this experiment the muscular and skeletal respiratory mechanism of the thorax was reduced to a ring, formed by three ribs with their intercostal muscles and a section of the sternum. The three ribs were severed from the rest but retained their articulations with the vertebral column as well as the vascular and nervous supply to the intercostals. When the tension of CO_2 in the blood was allowed to increase by arrest of artificial respiration, the ring moved forwards and backwards with a slow steady rhythm; forwards by contraction of the external intercostals, and backwards by contraction of the internal intercostals. Since the pulmonary alveoli were passive, the regulation of the rhythm must have depended upon the alternation of excitation and inhibition of the neuromuscular mechanism.

It may be suggested that the respiratory centre itself works with a rhythm of its own, but experimental evidence of the existence of such rhythmic automatism is still lacking[1]. It used to be believed that it was established by a well-known experiment of Rosenthal, who obtained rhythmic respiratory movements of the nostrils after he had supposedly cut off all afferent impressions from the centre. But the reciprocal innervation of muscles was then unknown, and the afferent impressions emanating from the muscles involved had not been cut off.

[1] Adrian and Buytendijk [1931] have shown that the isolated brain stem of the goldfish exhibits oscillations of potential synchronous with the respiratory movements of the gills, and consider that the waves represent a slow change in the nerve cells or dendrites, since they occur in the entire absence of sensory impulses. This observation certainly furnishes an argument in favour of the rhythm of respiration having a central origin—but the argument cannot be pressed too far, for the mechanism of respiration is quite different in fishes from the far more complex conditions found in mammals.

SUMMARY.

1. Respiration consists of inspiration and expiration: normally there is no pause.

2. No definite relationship obtains between the frequency of the pulse and that of quiet respiration, but usually there are 5 to 8 heart beats to each respiration.

3. Expiration is never a passive process but is always accompanied by muscular activity.

4. Although the regular rhythm of respiration is caused by the inflation and deflation of the pulmonary alveoli acting through the vagi it is assisted by afferent impulses emanating from the respiratory muscles. If the vagi are severed these impulses may be sufficient to maintain a normal rhythm.

5. It is doubtful if the respiratory centre has a rhythm of its own, independent of all reflexes. In the experiments which have been thought to prove its automatism the afferent impulses from the respiratory muscles have not been taken into account.

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