ON SOME CARDIAC REFLEXES. By F. A. BAINBRIDGE.

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BAYLISS(3) has demonstrated the existence of reciprocal innervation in vaso-motor reflexes, and it is often assumed that in reflex slowing or acceleration of the heart there is a similar balanced action between the vagus and the cardiac accelerators. The question does not appear, however, to have been directly studied in any of the numerous observations which have been made on cardiac reflexes, and the primary object of the present enquiry was to investigate it. This investigation has led to an analysis of the various factors concerned in reflex acceleration of the heart, and to the consideration of their general physiological significance.

Methods. Most of the experiments were carried out on dogs; cats and rabbits proved rather unsatisfactory mainly because of the comparatively slight vagus tone normally present in these animals. After a preliminary dose of morphia the dogs were anæsthetised with a mixture of chloroform and ether. A cannula was placed in the carotid artery; and one limb of the cannula was connected with a mercurial manometer which recorded the blood-pressure. The other limb of the cannula was attached to a Hürthle manometer which served to give a record of the pulse rate, since the reading of the mercurial manometer is often far from accurate. The respiratory movements were recorded either by means of a stethograph connected with a tambour, or by attaching the tambour to a side tube on the tracheal cannula. It is very important to avoid hæmorrhage, which partly by abolishing the tone of the vagus, partly by its general effects, renders it difficult and sometimes impossible to elicit the cardiac reflexes.

1. *Reflex slowing of the heart.* Although the production of reflex slowing of the heart by stimulation of the central end of one vagus and the disappearance of the reflex on section of the opposite vagus is so well established, the presence or absence of accelerator tone does not appear to have been specifically examined in such experiments. In the

present enquiry the existence of a marked accelerator tone was demonstrated by the fact that the pulse rate after section of the vagi was frequently almost maximal as was shown by the failure of adrenalin, when injected into the circulation, to produce any further acceleration. In other experiments in which the pulse rate after section of the vagi was not very rapid, the accelerator tone was increased by stimulation of the central end of the sciatic nerve; this, as will be shown later, reflexly stimulates the accelerator nerves, and often causes a prolonged increase in their tonic activity. Even when the accelerator tone was well marked stimulation of the central end of one vagus (after section of both vagi) had no effect whatever on the pulse rate. It seems clear, therefore, that the slowing of the heart normally produced by stimulation of the central end of the vagus or the lingual nerve, is due solely to reflex vagus inhibition and that there is no evidence for the existence of any associated inhibition of the accelerator tone.

2. *Reflex acceleration of the heart.* As is well known, stimulation of the central end of many sensory nerves reflexly quickens the heart and also causes hyperpnœa and usually a rise of blood-pressure. The exact time relations between the circulatory changes and the hyperpnœa do not appear, however, to have been recorded. Cyon and Roy and Adami (15) attributed the acceleration to reflex stimulation of the accelerator nerves. Hunt (11), whose paper contains a summary of the earlier literature, concluded that it was due entirely to diminution of vagus tone; he failed to obtain any reflex acceleration of the heart after section of the vagi. Mac William (14) also took the view that the acceleration was due solely to diminution of the tone of the vagus. Hooker (10), however, brought forward evidence that after section of the vagi reflex acceleration of the heart could be produced.

In the present enquiry the nerve used for stimulation was the central end of the sciatic trunk. A typical result is shown in Fig. 1.

The latent period of the acceleration and of the hyperpnœa is very short, usually not more than 1–2 seconds. Occasionally the rise of blood-pressure is replaced by a fall, the varying effects upon the blood-pressure being possibly due to variations in the depth of the anæsthesia. The acceleration is equally readily obtained in a curarised animal and is therefore independent of muscular and respiratory movements, as is seen in Fig. 2.

The possible causes of this acceleration are (1) diminution of vagus tone, (2) reflex stimulation of the accelerator nerves, and (3) the setting free of adrenalin. The chief share seems to be taken by the vagi, since

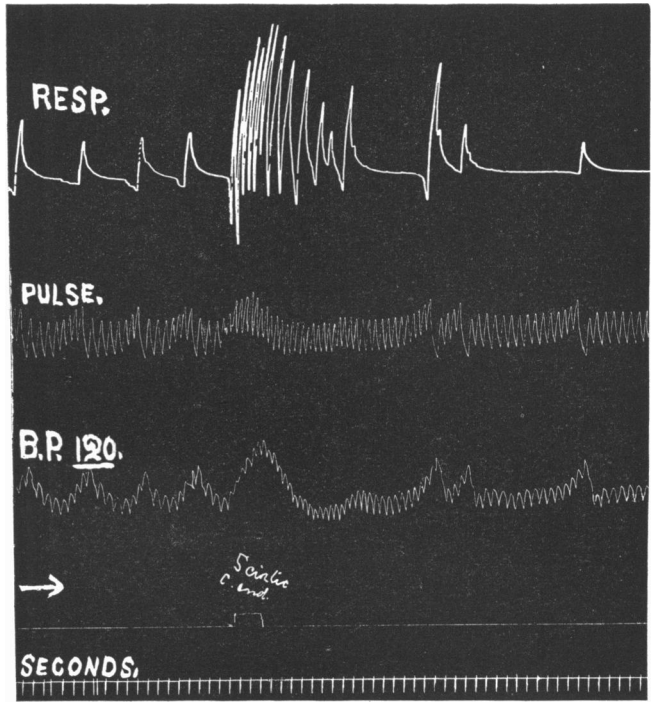
RESP.
PULSE.
B.P. 120.
Sciatic c. end.
SECONDS.

Fig. 1.

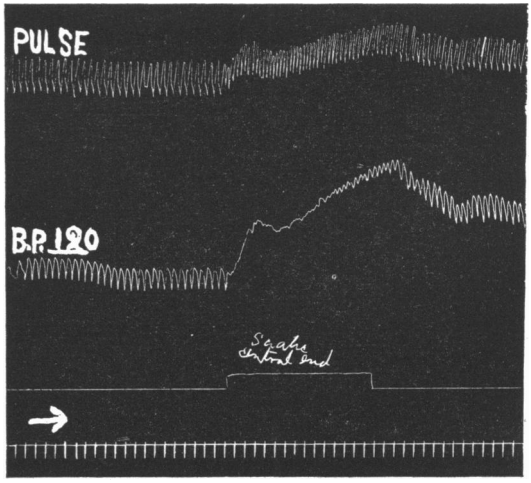
PULSE
B.P. 120
Sciatic central end

Fig. 2.

the acceleration is equally well shown after exclusion of the suprarenal glands from the circulation (Fig. 3), and stimulation of the central end of the sciatic nerve after removal of the stellate ganglia also causes an immediate definite acceleration (Fig. 4). Further the extremely short

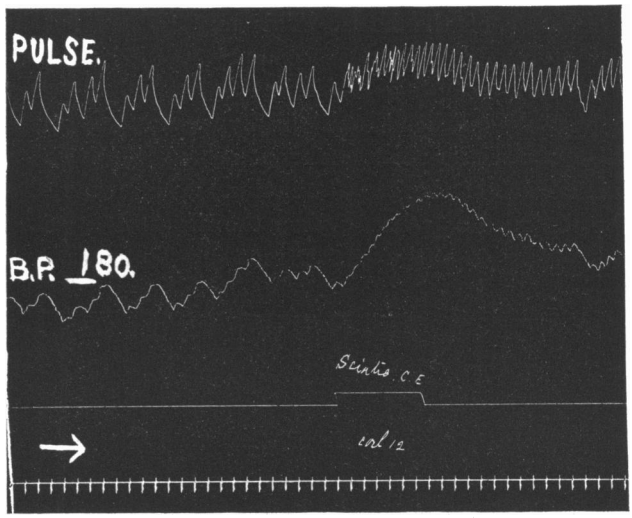

Fig. 3.

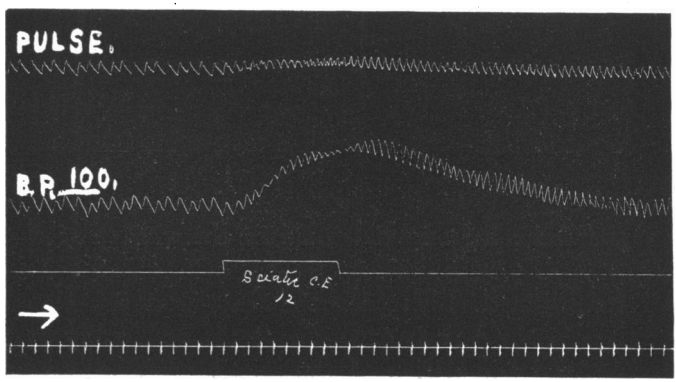

Fig. 4.

latent period shows that the initial effect at least cannot be due either to the accelerator nerves or to adrenalin.

Diminution of the vagus tone, however, is not entirely responsible for the acceleration since this occurs even after section of both vagi,

although it is often difficult to demonstrate owing to the rapid rate of the heart beat. The method employed by Hooker (10) for this purpose consisted in applying to the peripheral end of one vagus a current just strong enough to keep the heart beating at the rate previously observed in the intact animal. Intercurrent stimulation of the sciatic nerve then caused acceleration of the heart. This method has not been found entirely satisfactory in the present enquiry. The slightest escape of current alters the strength of the stimulus applied to the vagus and allows the heart to quicken; and the hyperpnœa accompanying the stimulation of the sciatic nerve makes it difficult to avoid such alterations in the strength of the vagal stimulus. The results thus obtained can only be regarded as reliable when the heart returns to its former rate after the cessation of the intercurrent stimulation (Fig. 5).

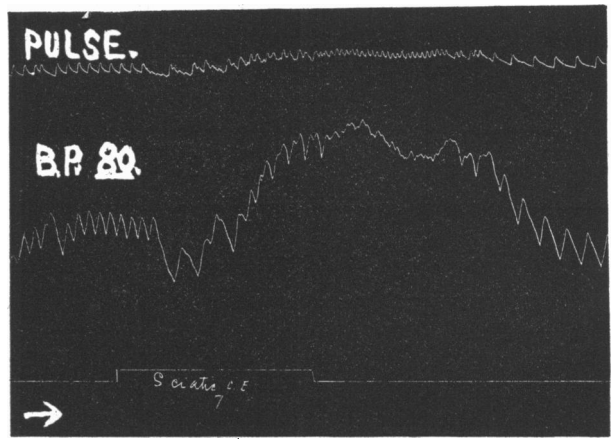

Fig. 5.

The vagus was being stimulated during the whole period shown in Fig. 5.

An alternative method is to slow the heart by means of a small dose of pilocarpin In some such experiments the respiratory system was not disturbed, and stimulation of the sciatic nerve led to a definite acceleration of the heart.

The most satisfactory results were obtained when, after section of the vagi, the heart-beat was not very rapid. The stimulation of the sciatic nerve then produced well-marked acceleration of the heart. It was found, however, that the acceleration tended to persist after the cessation of the stimulus, and that after the application of several stimuli

the heart continued to beat almost, or quite, at its maximal rate, since the injection of adrenalin (1 c.c. of 0·05 p.c.) produced no further acceleration. This observation suggested that one factor in the acceleration of the heart was an increase in the tone of the accelerators which, as Hunt found, when it has once occurred tends to persist throughout the experiment. The fact that (Fig. 6) acceleration of the heart was

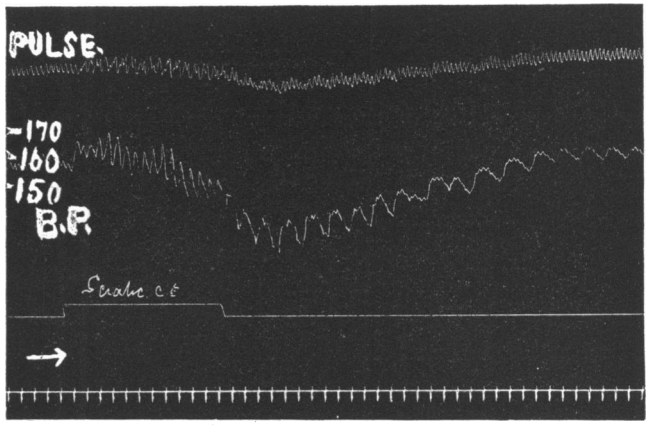

Fig. 6.

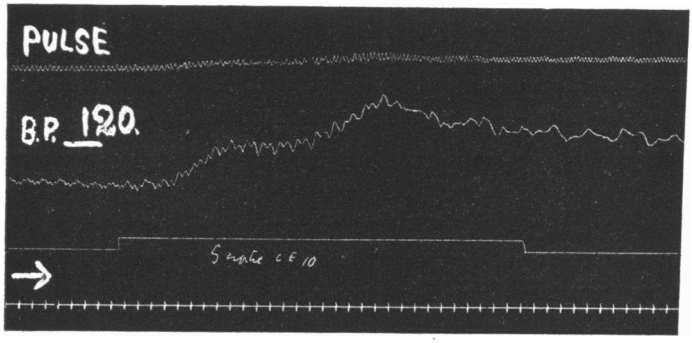

Fig. 7.

produced after exclusion of the suprarenal glands, and section of the vagi shows that this suggestion is correct, since in these circumstances the only nervous path to the heart is the accelerator nerves, and in the curarised animal the influence of movement is excluded. It has not seemed necessary to investigate very carefully the part played by adrenalin in this reflex acceleration since the work of Elliott (8),

Cannon (6), von Anrep (16) and others has shown so clearly that any reflex rise of blood-pressure sets free adrenalin into the circulation. One or two experiments have been made, however, in which the stellate ganglia were removed and the vagi divided; stimulation of the sciatic nerve produced acceleration of the heart (Fig. 7) after a latent period of from 6 to 8 seconds. Owing to the length of the latent period a rather prolonged stimulation of the sciatic nerve is necessary.

Discussion of results.

The reflex acceleration of the heart which follows stimulation of a sensory nerve (the sciatic) is brought about partly by diminution of vagus tone, partly by stimulation of the accelerator nerve, and partly by the entrance of adrenalin into the circulation. The vagus is the most important of these factors, and when the stimulus is weak, it is the only one which can be demonstrated to be present. Its importance is indicated by the fact that the acceleration of the heart, provided the vagi are intact, is as pronounced after the exclusion of the suprarenal glands as in the intact animal, and is very well marked after excision of the stellate ganglia. The readiness with which the vagus centre responds to stimulation of a sensory nerve, such as the sciatic, would seem to make the accelerator nerves comparatively unimportant. Gasser and Meek (9) regard them as a subsidiary mechanism which can be called into use at times of stress, and the fact that their tone often increases as the general condition of the animal deteriorates may perhaps be regarded as favouring this view. Although stimulation of the sciatic nerve can cause a transient acceleration of the heart, the stimuli tend, if prolonged or repeated, to produce a more persistent quickening which is due to a permanent increase in the tone of the accelerator nerves. In this respect, the reciprocal innervation involved in reflex cardiac acceleration does not fall strictly into line with most of the other examples of reciprocal innervation.

Considered as a whole the effects on the circulation and respiration brought about by stimulation of the sciatic nerve show a striking similarity to those observed in muscular exercise; in each case there is an immediate acceleration of the heart, a rise of blood-pressure, and hyperpnœa. The nervous origin of the hyperpnœa has been demonstrated by Krogh and Lindhard (13), and the recent work of Gasser and Meek (9) shows that the increased pulse rate occurring at the beginning of exercise is due mainly to a diminution of vagus tone (as

Miss Buchanan (5), Aulo (1) and Johansson (12) had suggested), and to a smaller extent to stimulation of the accelerator nerves, and the setting free of adrenalin. This similarity appears to be more than a mere coincidence. As Sherrington has pointed out, the essential response to a nociceptive stimulus is muscular movement, and it is probable that the visceral reflexes which occur either in response to a nociceptive stimulus or at the onset of muscular exercise, form a group, acting together as a single reflex. This can be evoked either by impulses from the cerebral cortex, as in exercise, or by impulses from the periphery. In exercise the visceral changes cannot be separated from the muscular movements, whereas in the anæsthetised animal they can be evoked, apart from muscular movement, by stimulation of a sensory nerve, such as the sciatic.

Conclusions.

1. It is known that stimulation of the central end of one vagus causes slowing of the heart by way of the other vagus, and in the experiments hitherto described the effect ceased on section of the opposite vagus. In these experiments, however, it was not shown that accelerator tone existed. The experiments have been repeated, in this enquiry, when accelerator tone was present; in no case does stimulation of the central end of the vagus slow the heart by decreasing the accelerator tone. There does not appear therefore to be any reciprocal action between the vagus and accelerator centres.

2. It is known that stimulation of the central end of the sciatic nerve causes acceleration of the heart in the anæsthetised animal (with or without curare); but there is a difference of opinion as to the cause of the acceleration. In these experiments it has been found to be mainly due to a decrease of vagus tone, but acceleration can also be caused by increase of accelerator tone; and it is brought about by reciprocal action between the vagus and accelerator centres.

Further, some late increase in the rate of the heart is produced by the setting free of adrenalin.

3. The effects on the circulation and respiration of stimulation of the sciatic nerve and of muscular exercise are very similar. It is suggested that the reflexes concerned in producing these effects form a group, acting as a single reflex, which can be evoked by impulses starting either from the cerebral cortex, or from the peripheral nervous system.

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