J. Physiol. (1941) 99, 257–264 612.211

A METHOD OF RECORDING THE RESPIRATION

By J. H. GADDUM

From the College of the Pharmaceutical Society,
17 *Bloomsbury Square, London, W.C.* 2

(*Received* 9 *September* 1940)

Most of the devices used for recording respiration fail to give a quantitative measure of the air breathed, since the record is affected not only by the depth of breathing, but also by the rate at which each breath is taken. The method described here avoids this fault, and gives a record on which the mean height above the base-line depends upon the total ventilation per minute.

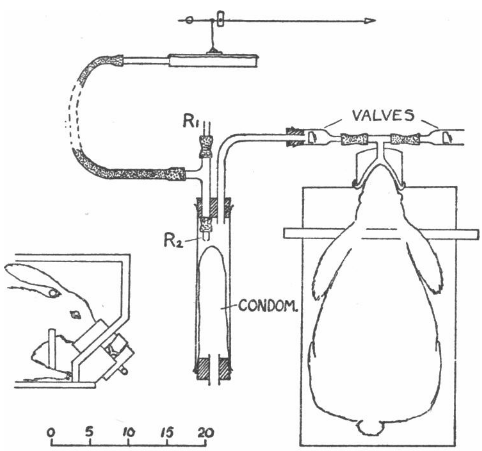

Fig. 1. Apparatus for recording the respiration of a conscious rabbit. The tambour records the fall of pressure in R_1, and thus the total rate at which the rabbit uses air.

The principle of the method is that all the air breathed by the animal passes, at an approximately steady rate, through a resistance (R_1), and a record is taken of the fall of pressure in this resistance. Fig. 1 shows the apparatus attached to a conscious rabbit by means of a mask. The mask consists of a small tin, on one end of which there is a rubber diaphragm pierced by a hole which fits round the rabbit's nose. A small

T-tube is soldered to the other end of the tin for attachment to valves. In order to diminish the dead space, the tin is filled with plaster of paris, which is moulded to the shape of a rabbit's head and covered with wax. In anaesthetized animals the valves can, of course, be attached to a T-tube which is tied in the trachea.

Valves. It is important that the valves should resist the respiration as little as possible; experiments have been made with various types. The inspiratory valves from service respirators have been found satisfactory both for rabbits and for larger animals. These consist of a rubber ring on to which fits a rubber flap which is thickened in the middle. A piece of rubber dam, fixed at one point so that it covers a hole in a rubber bung, has also been found satisfactory for rabbits. Neither type of valve had any very obvious effect on the respiration.

The tambour. The tambour, which gives a record of the fall of pressure in R_1, must be very sensitive, to give a record of convenient size without involving enough resistance to obstruct the respiration. The sensitivity depends upon many factors, including the amplification of the movement given by the lever, and the thickness and initial tension of the rubber. The most important factor is the diameter; large tambours are much more sensitive than small ones. The complete calibration curve is S-shaped, and the steepest part of this curve, where the sensitivity is greatest, corresponds to the point where the rubber is flat.

A tambour with a diameter of 11 cm., made from the lid of a tin and covered with medium rubber dam, has given satisfactory results. A round metal disk, weighing 5 g. and with a diameter of about 1 cm., was fixed in the middle of the rubber with sealing-wax, and attached to a light lever with a thread. The weight keeps the thread taut. The lever amplified the movement twenty times. A straight-edge was held across the rubber and the weight on the lever adjusted until the rubber was flat. This tambour gave a displacement of about 30 mm. for 1 mm. of water pressure, when calibrated with Casella's micromanometer.

If the thread is made to pass over a small cylinder which forms the axle of the lever, the movement may be amplified as much as 100 times. The sensitivity is then increased and the curve connecting the height of the record with the pressure applied to the tambour is approximately straight over the range of pressures actually used, but, for reasons discussed later, this is not an advantage.

Fig. 2 shows two tambours working in opposition to record the fall of pressure in a closed circuit. The two metal disks on the rubber are joined by two light, but rigid, wires and the lower disk is attached to the lever with a thread. The tambours are first adjusted to the correct distance apart, and the weight on the lever is then adjusted until the simultaneous application of the same pressure to both tambours has no effect on the record.

It has been found convenient to attach the mechanism of an electric bell to the stand holding the tambour, so as to set up vibrations which prevent the lever sticking on the drum. This vibrator may have to be adjusted so as to prevent resonance in any part of the mechanism.

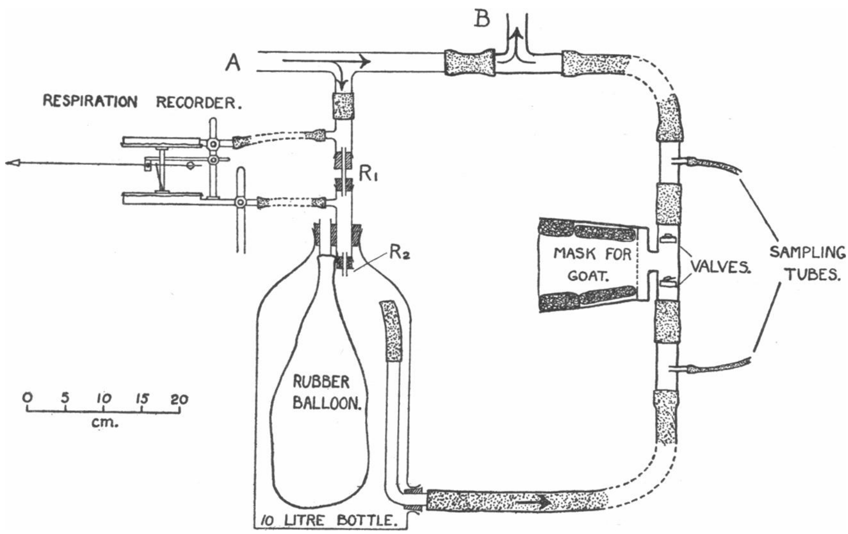

Fig. 2. Apparatus for recording the respiration of a goat, or man, with a closed circuit. A steady stream of air, to which gases can be added at known rates, passes from *A* to *B*. Two tambours, working in opposition, record the fall of pressure in R_1.

The resistance. The air is passed through the resistance, R_1, *before* it is breathed, because expired air tends to obstruct the resistance by depositing water in it. Were it not for this fact, it would be better to pass *expired* air through R_1, so that gases could be administered directly to the animal without passing either through R_1 or through the chamber containing the rubber bag.

The internal diameter of the tube forming R_1 varies from about 2 mm. for rabbits to 10 mm. for horses. The length is about 5 cm.

When the mean velocity of air in a tube is small, the air flows evenly down the tube and the fall of pressure is directly proportional to the rate of flow. When the flow is more rapid the air becomes turbulent, and for very rapid flows the pressure is proportional to the square of the flow. The relation between the flow (F) and the fall of pressure (P) can be approximately expressed by the equation $P = F^n$. The value of n can conveniently be determined by plotting log P against log F and fitting a straight line to the results. For slow flows $n = 1$; for rapid flows $n = 2$. Under the conditions of these experiments n has an intermediate value.

It may be calculated from the formula given by Ower [1933] that the critical flow, at which the air becomes turbulent, is 234*d* c.c. per sec., where *d* cm. is the diameter of the resistance. It would be, in various ways, convenient if the conditions could be chosen so that the rate of flow was below this critical value. In the first place, if the tambour was adjusted so that its calibration curve was straight, the calibration curve of the whole apparatus would then be straight. In the second place it can be calculated that, if the oscillations of the tambour were damped by placing a resistance between it and the rest of the apparatus, intermittent flows would give the same calibration as steady flows.

If the diameter of the tube forming R_1 is large enough to avoid turbulence, the sensitivity of the apparatus is seriously decreased. This may be avoided if the length of the tubing forming R_1 is increased, but, even with the most sensitive tambour, it was found necessary to use tubes over 1 m. long for rabbits and much longer tubes for larger animals. Since these tubes must be straight to avoid turbulence, the apparatus became unwieldy, and the attempt to avoid turbulence was abandoned.

The conversion of an intermittent flow into a steady flow. When the flow is turbulent and intermittent in R_1, the average fall of pressure, recorded by a damped tambour, depends not only on the total flow of air through R_1, but also on the wave form of the intermittent changes of flow. If the inspiratory valve is connected directly to such a resistance, rapid inspirations give higher records than slow inspirations, even when the total air breathed in a given time is the same. It is, therefore, necessary to use some damping device to prevent oscillations of flow from reaching R_1. In the apparatus shown in Fig. 1 the oscillations are taken up by a thin rubber condom, and prevented from reaching R_1 by a second resistance R_2, which should be made of slightly smaller tubing than R_1. Suitable glass tubes for both resistances are found by trial.

Fig. 2 shows a similar device, which has been used for goats and men; the oscillations are taken up by a large rubber balloon such as are used by meteorologists. If the capacity of the chamber which contains the balloon is sufficient there is no need for the balloon. The respiration of a horse has been recorded by using a chamber with a capacity of

10 cu. m. The horse wore a mask with valves, and inspired from the chamber and expired to the open air. The rate of flow of air into the chamber to replace that removed by the horse was recorded by attaching a tambour, between two resistances, to a hole in the chamber.

Calibration. The apparatus must be calibrated on each day that it is used, since the tambour tends to become gradually more sensitive owing to stretching of the rubber. The apparatus shown in Fig. 1 can

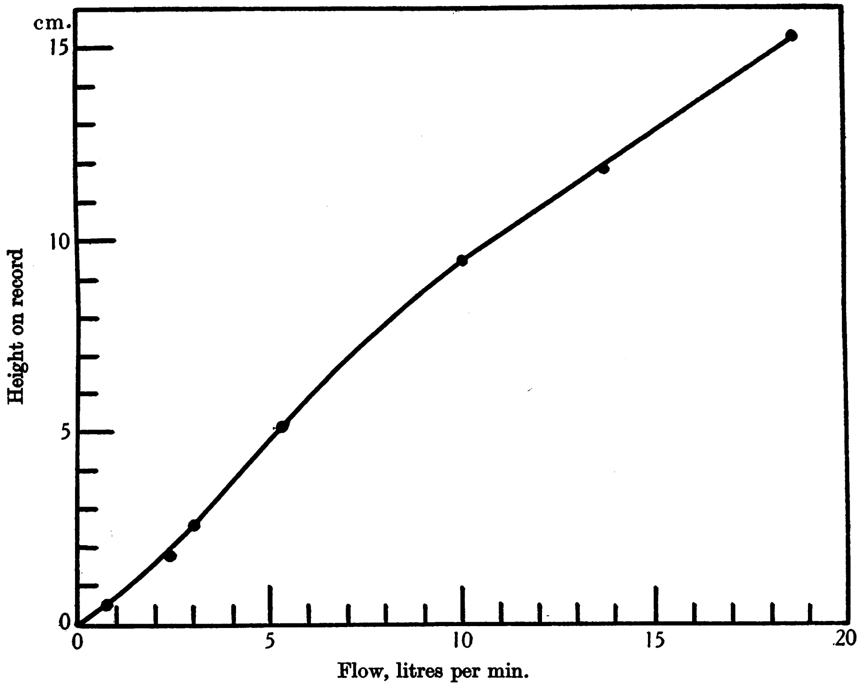

Fig. 3. Calibration curve, using a resistance made from a tube with an internal diameter of 6 mm. and a length of about 5 cm.

be calibrated by allowing water to run from one 10 litre bottle to another, and so sucking air through the resistances at measured rates. With larger rates of flow, the air can be sucked through a gas meter. In order to test the efficacy of the device for damping the oscillations the apparatus shown in Fig. 2 was calibrated both for steady and for intermittent flows. It was found that if the calibration obtained with a steady flow had been applied when the flow was intermittent, the average rate of flow would have been overestimated by about 10 %. This error is small compared with the variations between individual animals and was not considered important, since the main use of this type of apparatus is to record rapid changes of respiration. It could probably have been diminished by increasing the resistance at R_2.

If the flow is plotted horizontally and the fall of pressure vertically the curve is concave upwards when the flow is turbulent, and the sensitivity increases as the flow increases, so that the writing point is liable to go beyond the edge of the smoked paper. With the tambour

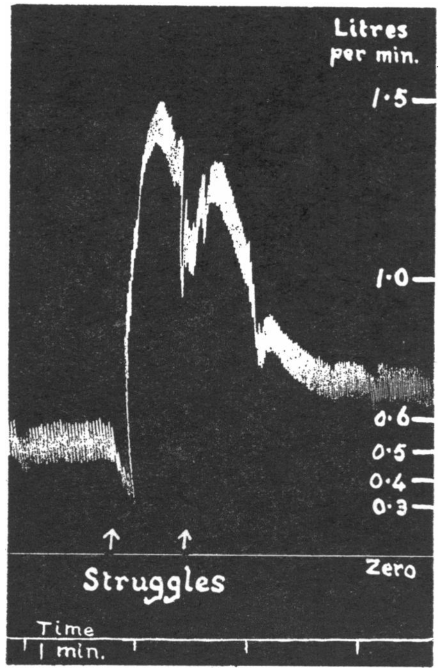

Fig. 4. Record of the respiration of a rabbit.

described above, this source of trouble is avoided since the calibration curve of the tambour itself is not linear over the whole range, and the tambour becomes insensitive when the record would tend to rise too rapidly.

These facts are illustrated by the shape of the calibration curve shown in Fig. 3, for which R_1 was a tube with an internal diameter of 6 mm. The curves obtained when tubes with internal diameters of 7 and 9 mm. were used, were the same shape provided that the horizontal scales were multiplied by factors of 0·54 and 0·25 respectively. These results are consistent with the finding that the resistance is proportional to the fourth power of the diameter of the tube [Ower, 1933].

When plotted on double logarithmic paper, the calibration curves become practically straight over the important part of their course, and the curves for different resistances are parallel.

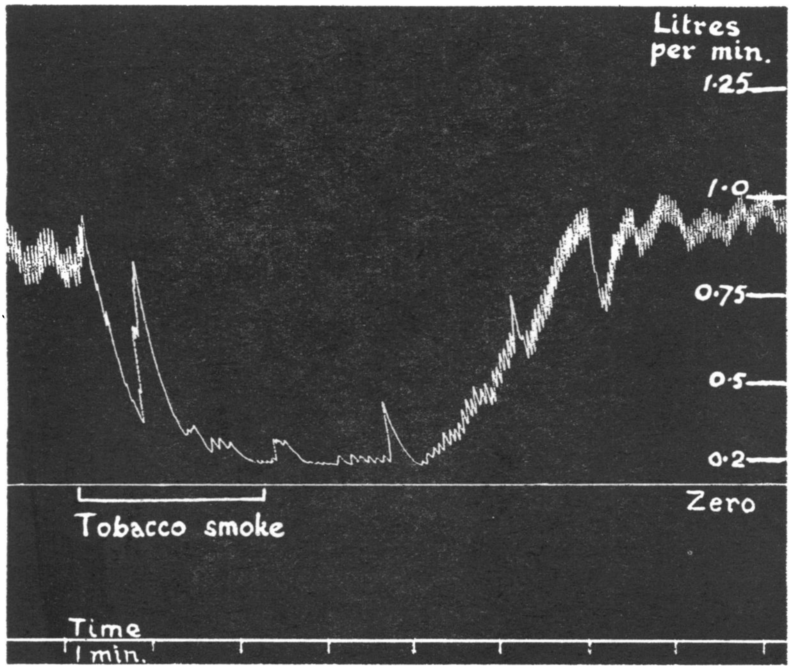

Fig. 5. Effect of tobacco smoke on the respiration of a rabbit.

Results

Fig. 4 shows the type of tracing obtained with a conscious rabbit, which at first sat very still and then tried to free itself from the mask. During the actual struggles there was a fall in the total ventilation, but this was followed by a large rise. Both the total ventilation and the rate of respiration were increased.

Fig. 5 shows the effect of holding a lighted cigarette near the inlet. The rabbit reduced its ventilation to about 20 % of its former value for several minutes ("Kratschmer's reflex").

SUMMARY

A simple method of recording the volume of air respired per minute is described. The method can be applied either to conscious animals or man or to anaesthetized animals.

REFERENCE

Ower, E. (1933). ***The measurement of air flow.*** **Chapman and Hall.**