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OXYGEN CONSUMPTION IN NEW-BORN RATS

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The rectal temperature of the new-born rat closely approximates to that of its environment. The ability of the rat to maintain a relatively constant body temperature in the cold is fairly well developed by the age of 3 weeks. Adolph (1957) concluded, largely from the work of Antoschkina (1939) and Fairfield (1948), that the new-born rat does not respond to cold with an increase in heat production (as indicated by an increase in O_2 consumption) until the age of 3–4 days. If this were true, then the new-born rat would differ from the new-born of most mammalian species in this respect. Rabbits (Giaja, 1925; Adamsons, 1959), cats (Leichtentritt, 1919; Hill, 1959), dogs (Gelineo, 1957; McIntyre & Ederstrom, 1958; Adamsons, 1959), pigs (Mount, 1959), sheep (Cross, Dawes & Mott, 1959), rhesus monkeys (Dawes, Jacobson, Mott & Shelley, 1960) and human infants (Day, 1943; Brück, Brück & Lemtis, 1958) all show a metabolic response to cold shortly after birth. Adolph's conclusion does not agree with the findings of Gelineo & Gelineo (1951) and Hahn & Koldovský (1958) which suggest that the new-born rat is to some extent capable of increasing O_2 consumption in the cold shortly after birth.

As the new-born rat is now so widely used in experimental work it was decided to determine in more detail the influence of age on minimal O_2 consumption, on the neutral environmental temperature at which O_2 consumption is minimal, and on the maximal increase in O_2 consumption that is observed with cooling. Observations were also made on the effect of varying the O_2 content of the inspired air on the O_2 consumption of young rats at the neutral environmental temperature, and on the effect of breathing 50 % O_2 on the metabolic response to cold. A preliminary account of this work has been given (Taylor, 1960).

METHODS

Wistar rats of either sex were placed in a glass chamber which formed part of a closed system of about 300 ml. volume, through which air was circulated at approximately 1·5 l./min by means of an aquarium aerator. Carbon dioxide was absorbed by soda-lime, and the oxygen consumed in the system was replaced automatically. As O_2 was consumed

the movement of a sensitive spirometer attached to the system opened a mercury contact, which started a roller-pump; this introduced O_2 into the system until the mercury contact was closed once more. The roller-pump was fed with oxygen from a second spirometer which was refilled once every 4 min. The movements of both spirometers were recorded on a smoked drum, as illustrated in Fig. 1. The closed system was almost entirely immersed in a water-bath maintained at constant temperature to within 0·1° C. After abrupt changes of bath temperature of 2° C the temperature within the system reached a new equilibrium within a few minutes. The O_2 content of the system was changed by flushing with O_2:N_2 mixtures at 1·5 l./min for 2–3 min, and the O_2 content of the effluent gas was measured with a Beckmann O_2 analyser, which was checked by gas analysis with a Haldane apparatus. The rate of O_2 consumption was corrected to and is expressed as dry gas at s.t.p.

Rats were removed from the nest immediately before the start of an experiment. The mother always accepted them back if they were returned at the end of the experiment. Usually 6–7 new-born rats were placed in the respiration chamber at one time; fewer rats were put in the chamber as their age and size increased. Three-week-old rats were, with one exception, investigated singly. Thus the total weight of the rats, or rat, used for each experiment was usually 30–40 g. The environmental temperature was lowered progressively in steps of 1–5° C (Fig. 2). O_2 consumption was recorded for three or more 4-min observation periods after a steady rate of O_2 consumption was reached following each change in environmental temperature. In experiments on the influence of the O_2 content of the inspired air on O_2 consumption, each test period was bracketed by periods during which the rats breathed room air. Blood was obtained by decapitation. Lactate was measured by Barker & Summerson's (1941) method, and glucose by the glucose–oxidase method (Huggett & Nixon, 1957).

RESULTS

Breathing air

All rats, even on the first day of life, showed an increase in O_2 consumption on exposure to a cold environment (Fig. 1). Figure 2 shows the rate of O_2 consumption in three experiments on rats aged 4 hr, 23 hr and 21 days (at the beginning of the experiment), at different environmental temperatures. The 4-hr-old rats (×) showed only a very small increase in O_2 consumption between 38 and 31° C. In the 23-hr-old rats (○) there was a large increase in O_2 consumption when the temperature was reduced below 36° C, and

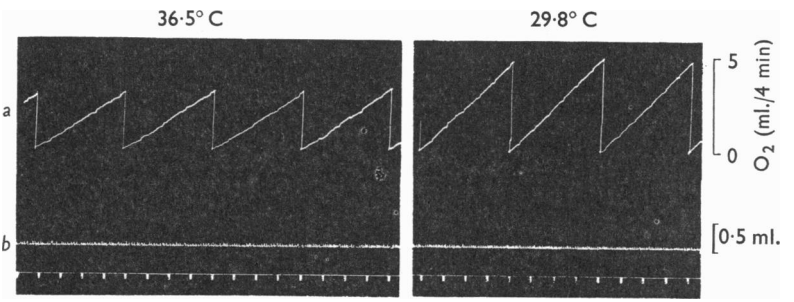

Fig. 1. Six rats, 19 hr old, 32·7 g in all. Records of O_2 consumption (*a*) and of closed-circuit volume (*b*) at an environmental temperature of 36·5° C (within the neutral zone) and at 29·8° C. Time marker, 1 min.

there appeared to be a neutral zone between 36 and 38° C. In the 21-day-old rat (●) the neutral zone extended from about 34 to 38° C, and below this there was a progressive increase in O_2 consumption down to 11° C, the lowest temperature studied.

These experiments illustrate the change in metabolic response to a lowered environmental temperature with increasing age. In the youngest rats, less than 6 hr old, which had not been suckled, there was only a trivial

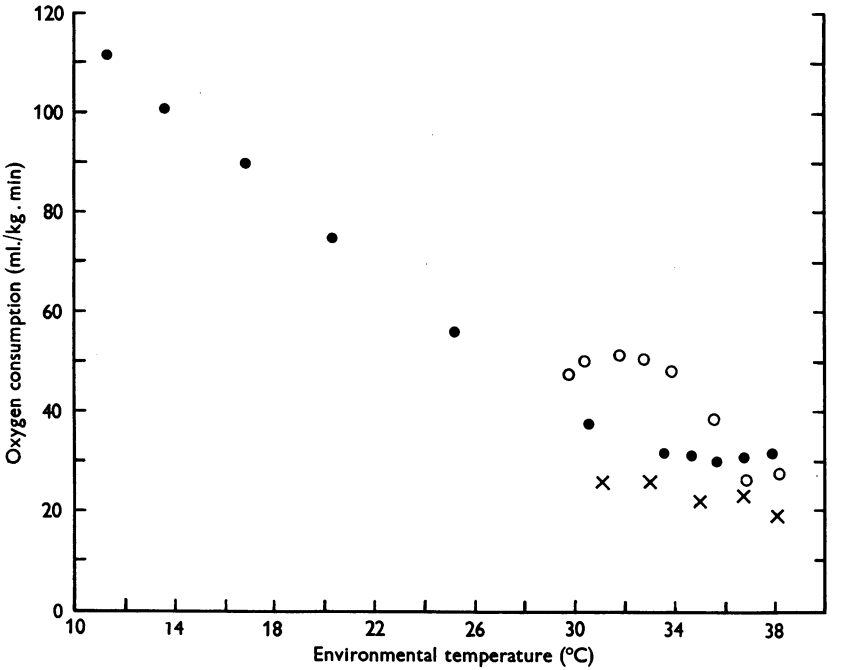

Fig. 2. Measurement of O_2 consumption per unit body weight at different environmental temperatures in a group of rats 4 hr old (×), in rats 23 hr old (○) and one rat 21 days old (●).

increase in O_2 consumption, and it was often difficult to define the neutral zone. Only five experiments on this point are illustrated in Fig. 3, in which are shown the minimal O_2 consumption at the neutral temperature (△) and the maximal O_2 consumption observed in the cold (▲). However, a number of other observations at this age confirmed these findings.

Between 6 and 48 hr of age there was a small increase in the minimal rate of O_2 consumption recorded at the neutral temperature, from a mean of 19·7 to 28·7 ml./kg.min (Fig. 3, △, □, ○). There was little further change over the next 3 weeks. The maximal oxygen consumption on exposure to cold increased rapidly in rats which had been suckled (i.e. more than 6 hr old) to about 50 ml./kg.min at 48 hr of age, and thereafter more slowly

(Fig. 3, ●, ■). In rats which were 3 weeks old O_2 consumption increased from about 30 ml./kg.min at the neutral temperature to as much as 112 ml./kg.min in the cold. This may not have been the maximum possible O_2 consumption because, as in the experiment illustrated in Fig. 2 (●), the environmental temperature was not reduced below 10° C.

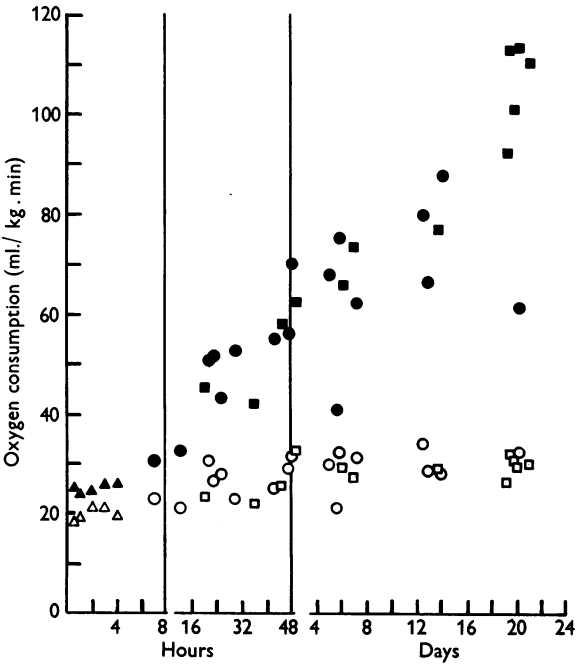

Fig. 3. The minimal (△, ○, □) rate of O_2 consumption at the neutral temperature and the maximal rate (▲, ●, ■) in a cool environment has been plotted for rats of different ages, before suckling (△, ▲) and placed in the respiration chamber either together (○, ●) or separated by partitions (□, ■).

Figure 4 shows the range of the neutral temperature zone (vertical bars) and the temperature at which O_2 consumption was maximal (×) at different ages. The neutral zone varied considerably in rats of the same age. Five of the seven litters of ½–12-hr-old rats had relatively low neutral environmental temperature zones (33–35·5° C) while the other two litters of rats of this age had higher neutral environmental temperatures, similar to those observed for rats 18 hr to 14 days of age. Three-week-old rats had lower neutral environmental temperature zones, ranging from 30·5 to 36° C.

The environmental temperature at which the maximal rise in O_2 consumption was observed increased from 29·6 ± 0·7° C (S.E.) in ½–12-hr-old rats to 31·1 ± 0·4° C in rats 18–51 hr old. This difference is not significant.

There was a fall in this temperature between 2 and 5 days after birth which continued to 3 weeks. The figure given for the temperature at which O_2 consumption was maximal in four of the six 3-week-old rats may be too high.

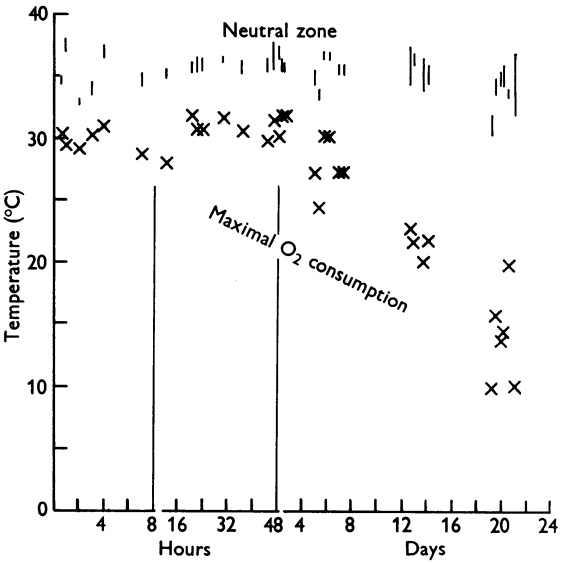

Fig. 4. The range of neutral environmental temperatures (vertical lines) and the temperature at which O_2 consumption was maximal (×) plotted against age from birth.

Hill & Hill (1913) showed that, when 2-month-old rats were placed together in a calorimeter, their heat production dropped considerably below that of rats studied singly. Litters of rats 1–14 days old were therefore divided, and one half was placed together in the respiration chamber while the other half was segregated, one from the other, by double partitions. In a number of such experiments the rates of O_2 consumption were compared at the neutral temperature and in the cold. The differences observed were such as to be expected, in that the neutral temperature was a little lower and the maximal increase in O_2 consumption was a little higher in the grouped than in the separated litter-mates. However, as Fig. 3 (□, ■) shows, these differences were small, particularly when compared with the very large changes observed with increasing age.

The rats were in direct contact with the glass wall of the respiration chamber, which was immersed in water at a temperature about 0·5° C lower than that of the air in the respiration chamber. Antoschkina's (1939) observations suggest that the rectal temperature of the rats would be 1–2° C higher. It seemed possible that the rats might lose heat rapidly

because they were normally placed in direct contact with the glass, which has a relatively high thermal conductivity. To test this possibility groups of young rats were placed alternately in the glass cylinder or in a Perspex cylinder lined with cardboard, both at the neutral temperature and in the cold. There was no significant difference in O_2 consumption in the two cylinders.

The rats were least active at the neutral temperature; the unfed new-born rats were more active than any others. As the temperature was reduced, by steps of 1–2° C, all the rats showed increased activity, which usually subsided somewhat within a few minutes. With extreme reduction of temperature, to below 30° C in new-born rats and below 15° C in 3-week-old rats, they became torpid. The rate of respiration, and the depth so far as it could be judged, increased in all rats in a cool environment. Slight shivering was always seen in 3-week-old rats below 20° C, but not in younger rats. Rats less than 12 days old have little hair; pilo-erection was apparent in the cold by 2 weeks of age, when blanching of the skin was also seen. In new-born rats the skin was very red and did not change colour when the environmental temperature was reduced to just below 30° C, when O_2 consumption began to decrease.

When the environmental temperature was raised above the neutral zone, as shown by an increase in O_2 consumption, there was a considerable increase in activity at all ages. This increased activity persisted in very young rats, but soon subsided in older ones. The respiration rate increased in rats of all ages.

Breathing O_2 at high or low concentrations at the neutral temperature

Rats 0–1, 3–4 and 14–15 days old were exposed at the neutral temperature, which was determined while breathing room air in each experiment, to 50, 18, 15 and 10 % O_2 in that order. Each period of exposure was preceded and followed by 12–20 min periods, during which the rats breathed room air, as is shown in Fig. 5. The O_2 consumption while breathing room air remained constant during these experiments within 1–2 ml./kg.min, except after exposure to 10 % O_2.

Inhalation of 50 % O_2 was usually associated with a slight increase in O_2 consumption (Fig. 6). There did not appear to be any systematic difference with age. Most of the rats increased their activity on exposure to 50 % O_2; the 0–1-day-old rats sustained this increase for the period of exposure, but the activity of the older rats soon returned to the level observed when they were breathing room air.

A reduction in the O_2 concentration of the inspired air to 18 % or less in 0–1-day-old rats, in all but one litter, caused a considerable fall in O_2 con-

sumption (Fig. 6). There was an even greater fall when the O_2 concentration was lowered further. In older rats O_2 consumption was well maintained on 18 and 15 % O_2, but there was still a profound fall on 10 % O_2. All the rats showed increased activity and cyanosis on 15 % O_2; some of them became ashen coloured and developed slow gasping respiration on 10 % O_2. Even a short period of exposure to 10 % O_2 at the neutral temperature caused some deaths.

In three litters each of 8–10 rats 20–45 hr old the neutral temperature was determined while breathing room air. Half of each litter was removed

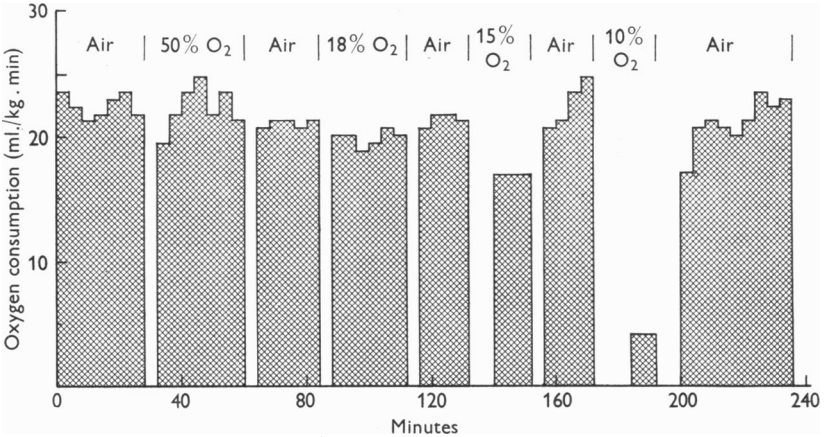

Fig. 5. Nine rats, 1 hr old, 48·0 g in all, at their neutral temperature, 35·7° C. Administration of 50 % O_2 caused little change in O_2 consumption, but 18 % O_2 or less caused a fall in O_2 consumption.

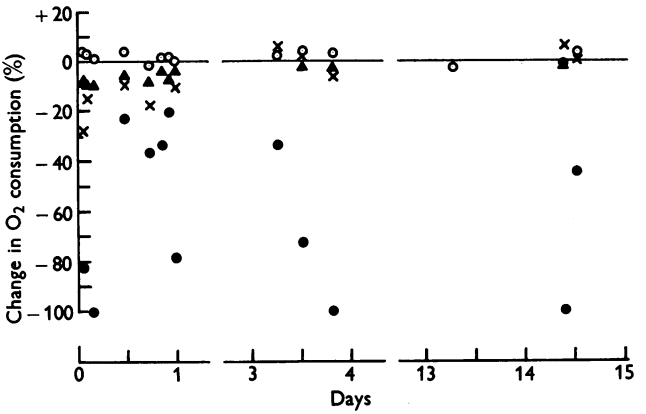

Fig. 6. Observations on rats of different ages, all at the neutral temperature, of the change (%) in O_2 consumption as compared with that breathing room air, on exposure to 50 % O_2 (○), 18 % O_2 (▲), 15 % O_2 (×) or 10 % O_2 (●).

and the blood lactate was determined. The other half was exposed to 15 % O_2 for ½ hr, and the blood lactate was then found to be considerably higher than that of their litter-mates (Table 1). In only one rat breathing air was the blood lactate as high as that of any of its litter-mates breathing 15 % O_2. There was no significant difference between the blood glucose levels of the two groups of rats.

TABLE 1. Mean blood lactate levels in new-born rats exposed to air or to 15 % O_2 for ½ hr

Litter	Mean blood lactates (mg/100 ml.) Breathing air	Breathing 15 % O_2
A	14·1	23·4
B	13·7	19·2
C	14·9	31·5

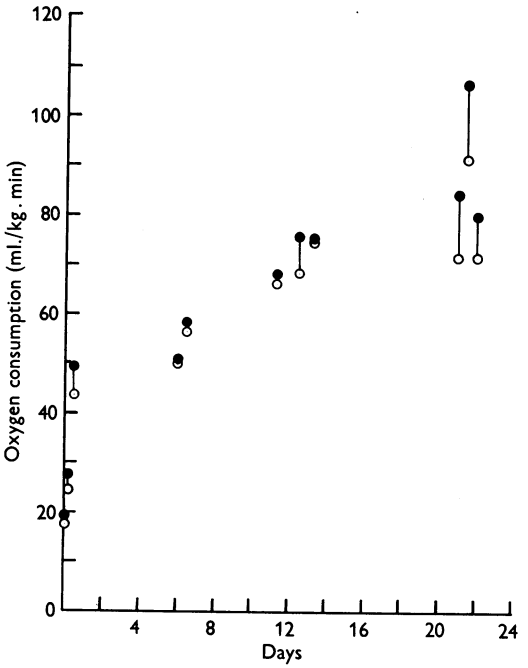

Fig. 7. Observations on the O_2 consumption of rats of different ages, at temperatures such that O_2 consumption was near maximal, breathing either room air (○) or 50 % O_2 (●).

Breathing 50 % O_2 in the cold

Rats 0–½, 6–7, 11–13 and 21–22 days old were exposed for about ½ hr to 50 % O_2, at the environmental temperatures predicted (from Fig. 4) to stimulate the maximal metabolic response to cold. Each period of ex-

posure to 50 % O_2 was bracketed by periods of about ½ hr during which the rats breathed room air.

Breathing 50 % O_2 (Fig. 7, ●) was associated in each experiment with a small increase in O_2 consumption, when compared with the mean of the O_2 consumption values for the periods when the rats breathed room air (Fig. 7, ○). The absolute increase in O_2 consumption was greatest in the oldest rats. However, when expressed as a proportion of the control values, both 0–½ and 21–22 day-old-rats had increases of 9–15 %, and most of the 6–7 and 11–13-day-old rats had smaller increases. All the rats showed increased activity on 50 % O_2. The 21–22-day-old rats, which shivered slightly in room air, began to shiver more vigorously and more frequently when placed in 50 % O_2; shivering became weaker when they were returned to room air. The 11, 12 and 13-day-old rats did not shiver when breathing room air, but began to shiver slightly several minutes after they were put in 50 % O_2; shivering then persisted when they were returned to room air. The 0–½ and 6–7-day-old rats did not shiver on exposure to the cold in either air or 50 % O_2.

DISCUSSION

The metabolic response to cold

The results demonstrate that the O_2 consumption of the new-born rat increases when the environmental temperature is lowered from 35 to 29° C, thus confirming the findings of Gelineo & Gelineo (1951). Antoschkina (1939) likewise found an increase in the O_2 consumption of 2–7-day-old rats when the environmental temperature was dropped from 35 to 20–30° C, and Barić (1953) observed an increase in the O_2 consumption of 4–5-day-old rats when the ambient temperature fell from 38 to 30° C. On the other hand, both Gulick (1926) and Fairfield (1948) concluded that the rat does not increase O_2 consumption on exposure to cold for the first few days of life. It is likely that the large and abrupt drop in the environmental temperature from 35 to 20° C in Fairfield's experiments obscured, by rapid tissue cooling, any transient increase in O_2 consumption that her 0–3-day-old rats might have shown.

There was an increase in the metabolic response of the rat to cold between the ages of 4 and 24 hr (Fig. 3). This also is consistent with the observation by Gelineo & Gelineo (1951) that rats 3–5, 13–15, and 23–25 hr old, at an environmental temperature of 29–30° C, had O_2 consumptions of 26, 42 and 57 ml./kg.min, respectively. The further, more gradual, increase in the rat's maximal O_2 consumption in the cold between 24 hr and 3 weeks of age agrees well with Antoschkina's findings (1939). Recalculation of her data shows that the maximal O_2 consumption in the cold rose from 62 ml./kg.min in 2–7-day-old rats to 112 ml./kg.min in 3–4-week-old

rats. The metabolic response to cold also increases in dogs from birth to 3 weeks of age (Gelineo, 1957; McIntyre & Ederstrom, 1958), and also in monkeys (Dawes *et al.* 1960), and in human infants from birth to 9 days of age (Brück *et al.* 1958).

The most striking increase in the metabolic response of new-born rats to cold occurred soon after they had begun to feed. Barić (1953) found that 4–5-day-old rats, unfed for 24 hr, showed a decrease in O_2 consumption when the environmental temperature was lowered from 38 to 30° C. Mourek (1958) also observed a large decrease in O_2 consumption in 2–3-week-old rats studied at 26° C after a 24-hr fast. Therefore the small metabolic response to cold in unfed rats may be related to lack of carbohydrate reserves. Certainly there is a very large rapid fall in liver glycogen in rats after birth (Stafford & Weatherall, 1960).

Factors other than feeding might modify the metabolic response to cold during the first hours of life. The new-born rabbit (Adamsons, 1959) and the new-born lamb (Cross *et al.* 1959) show a considerable increase in both the minute volume of breathing and in O_2 consumption when changed from the neutral to a cold environment. An inadequate ventilatory response might limit the O_2 consumption of the new-born rat, as might the pulmonary diffusion capacity for O_2, the rate of pulmonary capillary blood flow, or the transfer of O_2 from the blood to the tissues. Exposure of new-born rats in the cold to 50 % O_2 caused only a small increase in O_2 consumption, less than the increase which was observed with increasing age (Fig. 7). It therefore seems unlikely that the metabolic response to cold in new-born rats is limited to any significant extent by the uptake of O_2 by the lungs. It is probable that the increase in the metabolic response to cold with age represents, in part, an adaptation to the change in environmental temperature from about 38° C *in utero* to the nest temperature of about 32° C.

The gradual increase in the maximal O_2 consumption in the cold between 1 day and 3 weeks of age takes place during a time of rapid improvement in the rat's ability to maintain a relatively stable body temperature in the cold. This improvement in thermoregulation is due, in part at least, to factors that reduce heat loss (Adolph, 1957). Therefore it is not possible to conclude that the maximal potential for heat production of a 3-week-old rat is superior to that of a 1-day-old rat at a given cool environmental temperature, since the heat production of the younger rat will be depressed to a greater extent than that of the older rat by its lower body temperature. Nor is it justifiable to compare the O_2 consumption of immature rats of different ages at the same body temperature, as the environmental temperatures, and therefore the skin temperature gradients (which probably provide stimulation for increased heat production), will be different at different ages.

The results also confirm Antoschkina's observations (1939) on the progressive decrease in the environmental temperature at which the maximum metabolic response to cold occurs between birth and 3 weeks of age. The progressive improvement in thermoregulation in the cold explains this change.

Minimal O_2 consumption in new-born rats

Three studies carried out on young rats at or near the neutral temperature must be considered. Gelineo & Gelineo (1951) found an increase in O_2 consumption from 19 to 28 ml./kg.min between the ages of 3–5 and 23–25 hr in rats investigated at 35–36° C. Fairfield (1948) in experiments at 35° C observed an O_2 consumption of from 21 to 36 ml./kg.min in rats 0–17 days of age, and found no correlation between O_2 consumption and age. Antoschkina (1939) noted mean values of 36–42 ml./kg.min in 2-day–3-week-old rats at 35° C. The minimal O_2 consumption increased 32% in the present investigation, from a mean of 19·7 ml./kg.min in 0–7-hr-old rats to a mean of 28·7 ml./kg.min in 2-day-old rats; this agrees well with the findings of Gelineo & Gelineo. The data on minimal O_2 consumption for rats 18 hr–3 weeks old are within the range of Fairfield's observations and below the mean values given by Antoschkina. The explanation for this discrepancy is probably that some rats from 1 to 14 days of age have their neutral temperature above 35° C, at which Antoschkina made her measurements.

An increase in O_2 consumption shortly after birth has been found in all the mammalian species in which this has been investigated. This increase is two- to threefold in lambs (Dawes & Mott, 1959), monkeys (Dawes *et al.* 1960) and pups (Gelineo, 1957) studied at the neutral temperature. Mount (1959) noted a 50% increase in O_2 consumption in pigs at 30° C (several degrees below their neutral environmental temperature) between 10–18 hr and 1–6 days. It can be estimated from his Fig. 3 that a 20% increase in O_2 consumption occurred over this period of time in pigs studied at 36–38° C, which is at or above their neutral temperature. Brück *et al.* (1958) found a trivial increase in the O_2 consumption of full-term human infants between birth and 4–6 days of age. They were investigated at 32–35° C, which may be the neutral environmental zone for the infant, though more information is required. Cross, Tizard & Trythall (1958) noted a 20% increase in O_2 consumption between birth and 3 days of age in full-term and premature infants, but it is likely that these infants were below the neutral environmental temperature.

It will be seen that the increase in minimal O_2 consumption after birth is certainly much less in rats than it is in lambs, monkeys and puppies. This might be due to the relative immaturity of the rat at birth, but it is

also pertinent that the rat increases in weight about sixfold during the first 3 weeks of life. Consequently we should expect the ratio of surface area to weight to be halved during this period and, other things being equal, the metabolic rate per unit body weight to decrease in proportion.

The neutral temperature zone in young rats

One of the principal reasons for undertaking the experiments which have been described was to define the neutral temperature zone in rats, its variation with age and its variation from one litter to another at the same age. The neutral environmental temperature drops from about 35° C at 2 weeks of age (Fig. 4) to the adult range of 28–30° C between 6 weeks and 2 months of age (Benedict & MacLeod, 1928; Antoschkina, 1939). The beginning of the fall in neutral environmental temperature coincides in time with development of effective insulation by the young rat (Adolph, 1957). The neutral temperature is also higher in the new-born dog (McIntyre & Ederstrom, 1958) and in the new-born human baby (Brück *et al.* 1958) than in the adult of these species.

The difference that may occur between neutral temperature zones in young rats of the same age (Fig. 4) makes it imperative that the neutral zone should be defined in each experiment if one wishes to speak of minimal O_2 consumption with certainty. In some instances the neutral zone for rats during the first day of life was above 36° C; it was about 34° C at 3 weeks of age. The investigations carried out on young rats at environmental temperatures of 31° C or less, with the intention of determining the influence of age on minimal metabolism, must be considered in this light (Davis, 1937; Kibler & Brody, 1942; McCashland, 1951; Grad, 1953; Klieber, Smith & Chernikoff, 1956).

For the same reason, the observations of Mourek (1959) are also difficult to interpret. He measured the respiratory rate in rats of different ages, breathing air and during hypoxia, at 32 and 26° C. He chose 32° C as the most usual nest temperature (which would agree with my observations). However, 32° C was below the neutral environmental temperature for almost all rats aged 0–21 days (Fig. 4), and Dawes & Mott (1959) and Adamsons (1959) have shown that the ventilatory response of young rabbits to hypoxia varies with the environmental temperature below the neutral zone.

It is well known that the new-born rat will survive total anoxia in nitrogen for a very long period, about 28 min at 35° C (Stafford & Weatherall, 1960). The survival time, to the last gasp, falls rapidly after birth to reach the adult value of 2–3 min at just under 3 weeks. One of the possible factors in this remarkable change is the increase in minimal metabolic rate

after birth. The present experiments suggest that this is unlikely to be a factor of much importance, since in the rat the increase in minimal O_2 consumption is small, and occurs within 2 days of birth.

O_2 consumption and hypoxia at the neutral temperature

The decrease in O_2 consumption of the new-born rat at the neutral environmental temperature when placed in 18 and 15 % O_2 was unexpected. The minimal O_2 consumption of young kittens (Hill, 1959), and of new-born rabbits (Adamsons, 1959), lambs (Cross *et al.* 1959) and monkeys (Dawes *et al.* 1960) is not reduced until the O_2 concentration of the inspired air is lowered to about 10 % at the neutral temperature. New-born human infants show a decrease in heat production (Brodie, Cross & Lomer, 1957) and a decrease in O_2 consumption (Cross *et al.* 1958) when breathing 15 % O_2. It is not known that these infants were at the neutral environmental temperature; the extra metabolism in the cold is very susceptible to hypoxia.

Mourek (1959) has investigated the effect of breathing 10 % O_2 on the O_2 consumption of young and adult rats at 32–33° C, i.e. well below the neutral environmental temperature for the youngest rats, and above the neutral temperature for adult rats. He found a 70 % decrease in O_2 consumption in rats at birth, a progressively smaller decrease up to 4 weeks of age, and no decrease in adult rats. His results may be, in part, a reflexion of the decrease in the rat's neutral environmental temperature that begins at about 2 weeks of age. It is also difficult to compare the present values with the results of others on the effect of hypoxia on O_2 consumption of adult rats. Most of these studies were done at environmental temperatures of 22–25° C (Blood, Elliott & D'Amour, 1946; Rothschuh, 1947; von Flückiger, 1956); the neutral temperature zone of the adult rat is 28–30° C (Goto, 1923; Benedict & MacLeod, 1928). Lintzel (1931) has shown that the O_2 consumption of adult rats at low atmospheric pressure is much reduced at environmental temperatures below the neutral temperature. It can at best be inferred from these papers that a moderate decrease in O_2 consumption can be expected in adult rats when the O_2 concentration of the inspired air is lowered to about 10 % at or slightly below the neutral temperature.

O_2 consumption was well maintained in 3·5- and 14-day-old rats breathing 18 and 15 % O_2 at the neutral temperature. The most likely explanation of this difference between the new-born and the 3·5-day-old rat is that the ventilatory response to hypoxia increases over this time. Adolph (1957) has reported a marked increase in pulmonary ventilation in 1–2-day-old rats exposed to a low O_2 pressure (44 mm Hg $\simeq$ 6 % O_2), which regresses to near control values in a few minutes. Six- to nine-day-old rats respond

better to the same O_2 pressure and maintain the increased ventilation for an hour or more. The depth of breathing increased while respiratory rate changed little in these experiments. Yet these observations were made at an environmental temperature of 33° C or less (Adolph & Hoy, 1960) and hence may not be applicable to the present observations.

The decrease in O_2 consumption of new-born rats breathing low-O_2 mixtures could signify either inadequate uptake of O_2 (in which case blood and tissue pO_2 would fall and the resulting energy debt might be partially met by anaerobic glycolysis) or a decrease in blood flow to certain regions of the body. New-born rats are certainly hypoxaemic when breathing 15 % O_2, as they show generalized cyanosis and an increase in blood lactate (Table 1). This does not exclude the possibility that reduction of flow in certain vascular beds might further reduce the O_2 consumption of young rats in 15 % O_2.

O_2 consumption, shivering and hyperoxia in the cold

Gulick (1926) states that rats first shiver in the cold shortly before 11 days of age. In the present experiments shivering was noted regularly in 19–22-day-old rats, but was not seen in 12–14-day-old rats breathing room air. Observations on the increase in, or initiation of, shivering in young rats breathing 50 % O_2 are in accord with von Euler & Söderberg's (1958) finding that anaesthetized adult cats shiver more while breathing 100 % O_2. The modest increase in O_2 consumption of young rats breathing 50 % O_2 may be explained by the initiation or augmentation of shivering in 11–22-day-old rats, and the increase in activity seen in 0–22-day-old rats.

Mourek (1959) has compared the O_2 consumption of young and adult rats when breathing air or 100 % O_2 at environmental temperatures of 32–33° C. Rats 0–3 days old had a 22 % increase in O_2 consumption, while rats 3–4 weeks old and adult rats showed no change in O_2 consumption on 100 % O_2. The most likely explanation for the observations is the decrease in the neutral environmental temperature of rats that takes place between birth and 3 weeks of age (Fig. 4). Rats show little change in O_2 consumption on 50 % O_2 at the neutral temperature (Fig. 6) and Mourek's 3–4-week-old rats must have been at or near the neutral temperature.

SUMMARY

1. The rate of O_2 consumption was measured in unanaesthetized rats from birth to 22 days of age, at the neutral temperature and in the cold.

2. The mean minimal O_2 consumption, at the neutral temperature, of new-born rats which had not been suckled was 19·7 ml./kg.min. It rose to 28·7 ml./kg.min by 2 days, and remained at this level up to 3 weeks from birth.

3. The neutral temperature zone extended over a range of up to 2° C between 33 and 38° C for the first 6 days of life. It covered a wider and lower temperature range by 3 weeks of age.

4. On exposure to cold there was always a rise in O_2 consumption. This rise was small in rats which had not been suckled; it increased rapidly from 6 hr of age onwards. The rise was even greater by 21 days of age while the environmental temperature at which O_2 consumption was maximal fell from about 30° C to below 20° C.

5. At the neutral temperature exposure of 0–1-day-old rats to 18 %, 15 or 10 % O_2 in place of room air, caused a fall in O_2 consumption. Rats 3–14 days old maintained their O_2 consumption well on 18 or 15 % O_2, but there was a profound fall on 10 % O_2. The O_2 consumption of young rats did not change significantly on 50 % O_2.

6. In a cold environment, at which O_2 consumption was near maximal, exposure of 0–22-day-old rats to 50 % O_2 caused an increase in O_2 consumption.

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