16868

Survival Differences Breathing Air and Oxygen at Equivalent Altitudes.*†

HERMANN RAHN AND ARTHUR B. OTIS.

From the Department of Physiology and Vital Economics, The University of Rochester School of Medicine and Dentistry, Rochester, N. Y.

It can be shown on theoretical grounds[1] that when equivalent altitudes are chosen where the pO_2 of the inspired gases are identical breathing air and breathing 100% oxygen the resultant *alveolar* pO_2 in the lung are never the same unless the respiratory quotient is equal to unity. For example, if the alveolar pCO_2 is 40 mm Hg and the R.Q. = .8, the alveolar pO_2 is 8 mm lower breathing air than breathing 100% oxygen. Under the same conditions but with the R.Q. = 1.0 the alveolar pO_2 is the same. When the R.Q. is greater than 1.0 the alv. pO_2 is larger breathing air than breathing 100% oxygen. Thus at equivalent inspired O_2 tension altitudes the relative advantage or disadvantage of breathing air as compared to 100% oxygen is a function of the R.Q. This phenomenon has been referred to as the *R.Q. Effect* or *Nitrogen Dilution Effect* (the latter applies more specifically to conditions of R.Q. greater than unity). Acute exposure to low oxygen concentration induces hyperventilation which raises temporarily the respiratory quotient above 1.0. As long as the quotient remains above 1.0 it would be preferable to breath air rather than 100% oxygen at equivalent inspired O_2 pressures. Theoretically an advantage of only a few mm in alveolar pO_2 pressure is expected, but since in very low hypoxic environments a few mm pO_2 spell the difference between consciousness and unconsciousness it was felt that this nitrogen dilution effect might be demonstrable.

Method. Mice were conditioned to sit on a horizontal bar of ½" diameter suspended about 8 cm above the base of a large desiccator. The bottom was provided with a metal grid which electrically shocked the animal whenever it left the bar. Mice are very readily conditioned to this procedure and will immediately jump on the bar even when no current is sent through the grid. *Unconsciousness* was designated as that state where mice were no longer able to maintain themselves on the bar. This criterion has proven to be a very satisfactory index. The oxygen pressure was reduced by evacuating the desiccator by a pump. The rates of ascent on air and 100% O_2 had to be very accurately controlled so that the rates of change of the inspired pO_2 (B.T.P.S.) were identical in the two runs. Thus the timing of air runs started at ground level where the inspired pO_2 was .209 x (B-47). In the 100% O_2 runs the desiccator was first thoroughly flushed with oxygen for several minutes. This was followed by a slow ascent to an altitude of approximately 32900 ft. to allow for denitrogenation. The timing of the pure oxygen runs was started at this altitude where the inspired pO_2 (equal to B-47) was the same as at ground level.

Usually 6 mice were "taken up" at one time and the inspired pO_2 was calculated from the altitude at which unconsciousness set in. The air temperature on all runs was kept between 22.9 and 24.1°C.

Since the N_2 dilution or R.Q. effect is a transient affair depending upon the degree of hyperventilation and the magnitude of the CO_2 reserve of the blood and tissues, the rate of ascent was varied as indicated in Table I. The rates of ascent so listed are based upon 100% oxygen runs which started at 32900 ft. The ascents on air were adjusted in such a

* This work was done under a contract recommended by the Committee on Medical Research between the Office of Scientific Research and Development and the University of Rochester. For continued support since 1946, we are indebted to a contract with the Air Materiel Command, Wright Field, Dayton, Ohio.

† The authors are greatly indebted to Mr. James Holmes for his technical assistance.

1 Fenn, W. O., Rahn, H., and Otis, A. B., *Am. J. Physiol.*, 1946, **146**, 637.

TABLE I.
Oxygen Tension (B.T.P.S. —37°C) of the Inspired Gas at Which Mice Developed Unconsciousness Breathing Air and Pure Oxygen.

Series	Rate of ascent 10^3 ft./min.	pO_2 on 100% O_2 mmHg	S.D. mmHg	n	pO_2 on air mmHg	S.D. mmHg	n	Δ mmHg	S.E.D. mmHg
I	0.5	23.3	12.2	23	24.6	1.7	23	—1.3	2.40
II	2.	41.7	7.6	33	32.5	5.6	35	9.2	1.63
III	4.	39.8	7.0	28	31.0	3.5	33	8.8	1.45
IV	16.	40.8	6.5	22	31.7	3.7	22	9.1	1.60

fashion that the inspired pO_2 at any time was equal to that of the O_2 runs.

Results and Discussion. Four different rates of ascent were tried. In Series I it took on the average 42 minutes to reach the unconsciousness level and there was no significant difference between the two runs. It might be argued that during this long interval the N_2 dilution effect was nearly over (the CO_2 reserves used up) as has been found for altitudes of 18-22000 in man.[2] Had a still slower rate of ascent been used where the R.Q. had time to return to its true metabolic value the tolerance on O_2 should have been better than on air. In such a case a N_2 concentration effect would have obtained.

In Series 2, 3 and 4 the rate of ascent was increased so that unconsciousness was reached after 6, 3 and 1 minutes respectively. It was felt that some of these ascent rates should catch the maximum N_2 dilution effect. This one would expect to be maximal at the beginning of hypoxic ventilation. It can be seen that all 3 rates gave approximately the same difference in pO_2 level at which unconsciousness was produced. All these differences are highly significant as indicated by the standard error of the differences between the means as shown in the last column of Table I. The pO_2 difference can also be expressed in terms of altitude. In other words, if the N_2 dilution effect were not present in the air runs then the unconscious level would have been reached at an altitude of 28500 ft. (inspired pO_2 of 41) instead of 33000 ft. (inspired pO_2 of 31).

It should be pointed out that another factor might enter into the discrepancy of these two runs. That is the possible occurrence of aeroembolism in the oxygen runs which by itself may contribute to the lower pO_2 threshold. Furthermore, the criterion of the inspired pO_2 at B.T.P.S. ($T = 37°C$) is probably not strictly true at very low hypoxic levels when the metabolism and the body temperature sink rapidly in these small animals. This temperature drop would increase the pO_2 tension. However, this should affect both series and if effective at all would favor the 100% O_2 animals.

Summary. Mice were exposed progressively to equivalent degrees of hypoxia breathing air and breathing 100% O_2. The inspired pO_2 level at which unconsciousness set in was found to be significantly lower when air was breathed than when 100% oxygen was breathed provided the rate of ascent was 2×10^3 ft/min or greater. This advantage of air over oxygen is attributed to the transient "N_2 dilution" or R.Q. effect.

[2] Rahn, H., and Otis, A. B., *Am. J. Physiol.*, 1947, **150**, 202.