CHANGES IN RESPIRATION DURING ACCLIMATIZATION IN THE INTERIOR OF ANTARCTICA

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The climate of the interior of Antarctica combines the characteristic features of a high-mountain climate with the specific polar conditions. The effect of this combination of man has not been discussed in the literature, although fairly detailed studies have been made of the action of both high-mountain and polar conditions separately. An increase in the rate and depth of respiration has been found at high altitudes [1, 9, 14, 16]. Most investigators have observed hyperventilation within a few minutes of exposure to hypoxia. Z. I. Barbashova [4] and N. K. Vereshchagin and V. B. Boldyrev [6] consider, however, that the increase in pulmonary ventilation develops very gradually during acclimatization to high altitudes. Hyperventilation usually does not develop before a certain threshold altitude has been reached: a height of 3000 m is usually mentioned [3, 8, 11, 13]. N. I. Averin [2] found no significant changes in pulmonary ventilation in persons living at an altitude of 2000 m. Investigation of the alveolar air revealed a considerable decrease in the CO_2 and oxygen pressure, as a result of which the blood oxygen saturation was lowered [7, 8, 15, 19]. Harvath and co-workers [17] found an increase in pulmonary ventilation during exposure to cold. During the polar night, Lindhard [18] recorded a decrease in pulmonary ventilation of persons wintering in the Arctic, associated with a fall in the respiration rate and an increase in the partial pressure of carbon dioxide in the alveolar air.

EXPERIMENTAL METHOD

Investigations were conducted at the Soviet Antarctic Station "Vostok" (for an account of the conditions see our paper in this journal, No. 12, 1963).

We investigated the respiration rate at rest and during physical effort, the rhythm of respiration, the volume of the pulmonary ventilation, the composition of the alveolar air, the blood oxygen saturation, and the maximal duration of breath holding. Data were collected regularly each month. All the investigations were carried out in close to basal metabolic conditions (in the morning before breakfast, after a preliminary rest).

Respiration was recorded by a thermoelectric method: an ordinary meteorological thermopile was held at a distance of 15 cm from the mouth of the sleeping subject. As a result of the difference between the temperatures of the expired and inspired air, the difference between the temperatures of the two sides of the thermopile was increased during expiration, which was accompanied by an increase in the potential difference; during inspiration the potential difference was reduced. These variations in potential were recorded on an oscillograph. The composition of the gases of the alveolar air was studied with a Haldane's apparatus. The blood oxygen saturation was determined by the method of oxyhemography.

EXPERIMENTAL RESULTS

After the first few hours of their stay at the station, all the winterers had marked dyspnea at rest. Throughout the winter, especially when asleep, most of the investigated persons exhibited Cheyne-Stokes respiration (Fig. 2). They were usually aware only of the phase of more intensive respiration, but sometimes, at times of self-observation, they also noticed the phase of the respiratory pause, which frequently gave rise to considerable uneasiness. Some subjects complained that they were afraid to sleep at night for fear that they would stop breathing. They complained most often of dyspnea during the polar night. This was explained, firstly, by the fact that even a simple walk in the darkness through the drifting snow in heavy weatherproof clothing (often during a blizzard) requires considerable effort

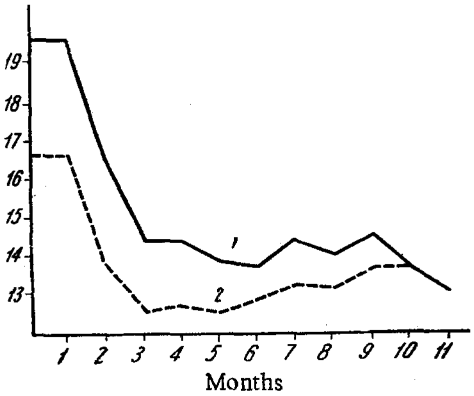

Fig. 1. Respiration rate (per minute) (1) and pulmonary ventilation (in liters/min) (2) at various times during the winter.

and is accompanied by an increase in pulmonary ventilation; secondly, respiration in the icy air becomes more superficial, and during a deep inspiration laryngeal spasm is frequently observed; in these circumstances the hypoxia becomes still more severe and for a time the person may almost lose consciousness.

During the first days of their stay at the station, the respiration rate of the winterers rose slightly (Fig. 2), but gradually slowed thereafter, and at the end of the winter period it amounted in most subjects to 11-13/min. During physical exertion the respiration rate rose sharply, especially during the first months. Whereas at the beginning of the winter period the respiration rate after squatting 15 times exceed 10/min in 8 subjects, at the end of the winter it was not more than 5/min.

The pulmonary ventilation reached its highest value during the first days of their stay at the station, after which it fell gradually (Fig. 1), reaching its minimal level during the polar night. With the appearance of the polar day the ventilation volume again increased slightly, but even at night the pulmonary ventilation exceeded the normal value by 50%. If the volume was reduced to normal conditions (0°, 760 mm Hg), it was very little different from the normal value. Throughout the winter a gradual increase in the tidal air volume was observed.

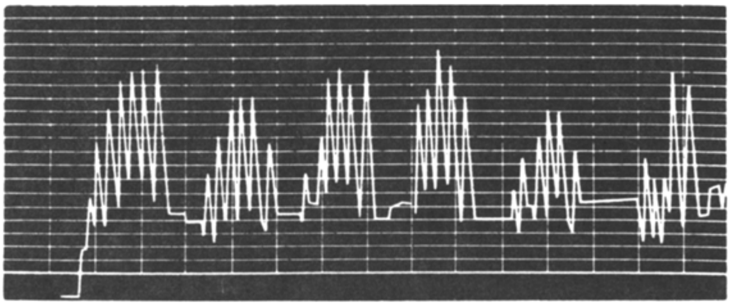

Fig. 2. Characteristic respiratory rhythm of winterers during sleep (recording of subject T. on July 17, 1959).

The changes in external respiration described above indicate a considerable degree of adaptation to the new environmental conditions. At first the body reacted to the oxygen lack by an increase in pulmonary ventilation caused by a faster rate of respiration; later the depth of respiration was increased.

The composition of the alveolar air was studied 5 times between February and April. Altogether 20 air samples were tested. The results of the analyses showed that one month after the beginning of the winter period the composition of the alveolar air became stabilized at what must be regarded as a new physiological norm for the particular environmental conditions. This level corresponded to a partial oxygen pressure of 53-56 mm Hg and a carbon pressure of 26-29 mm Hg. It may be noted that, despite the marked hypocapnia, the level of the pulmonary ventilation remained high.

The blood oxygen saturation was investigated by means of an oxyhemograph as follows. After allowing sufficient time for the apparatus and the subject's ear to warm up, 7-8 deep inhalations of oxygen were made, so that the blood oxygen saturation reached 100%, whereupon the apparatus was calibrated. The subject then breathed ordinary air quietly. In normal conditions the level of physiological hypoxemia when breathing ordinary air usually did not exceed 3-4%; nevertheless, a far greater fall in the blood oxygenation was observed. In individual subjects the blood oxygen saturation ranged between 88 and 76% at the beginning of the winter period, and subsequently the range of individual variations contracted to 87-82%. The next stage was investigation of the maximal forced hyperventilation. In ordinary conditions forced hyperventilation causes hardly any increase in the blood oxygen saturation. In our conditions for this test the saturation rose by 6-16%. The overall level of blood oxygen saturation reached 89-94%.

It may be noted that in persons with a higher level of blood oxygen saturation during quiet breathing, the increase in level as a result of hyperventilation was minimal. The next tests was Hench's test of maximal breath holding in expiration. The blood oxygen saturation during this test fall appreciably in all the winterers (to 76-60%), although the individual variations were considerable (from 6 to 18%). The duration of holding the breath also varied greatly. With the passage of time and in the course of acclimatization the duration of holding the breath gradually diminished, which does not accord with ideas of adaptation reactions of the third and fourth order [5]. Some workers have attributed this phenomenon to a decrease in the alkali reserve of the blood [12, 20] and others to increased excitability of the respiratory center [6], although the excitability of this center is, in fact, known to be raised during the period of the polar night [10].

We consider that the principal cause of this shortening of the breath-holding period during the polar night is a change in higher nervous activity—depression of the central nervous system, especially of the cerebral cortex, weakening the subject's ability to hold his breath voluntarily.

During physical exertion a considerable increase in hypoxemia (to 62-80%) was observed. In the course of acclimatization some increase was found in the degree of oxygen saturation of the blood at rest and after physical exertion (66-82%).

SUMMARY

Observations were made at the Soviet antarctic station, "Vostok". Tachypnea and considerable hyperventilation were observed during the first days after arrival at the station. With acclimatization, the frequency of respiration restored to the normal, pulmonary ventilation decreased, reaching the lowest level during the polar night period (however, even during that period it is $1\frac{1}{2}$ times greater than the normal value); the depth of respiration increased considerably. During the whole period of stay in Antarctica every individual had Cheyne-Stokes respiration, especially during sleep. Dyspnea increased considerably, even during slight physical strain. Composition of alveolar air became stabilized at a new level corresponding to a partial oxygen pressure of 53-56 mm Hg and to CO_2 pressure of 26-29 mm Hg. The blood oxygenation during quiet respiration was 80-87%, increasing with voluntary hyperventilation to 85-94%. Hypoxemia rose considerably with voluntary breath holding and physical strain.

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