EFFECT OF HYPERCAPNIA AND HYPOCAPNIA ON IMPULSE ACTIVITY OF INSPIRATORY AND EXPIRATORY NEURONS OF THE RETICULAR FORMATION OF THE MEDULLA

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The work of M. E. Marshak and co-workers [1-7] has shown that if the CO_2 tension in the alveolar air and arterial blood is reduced by hyperventilation, and also during apnea, the rhythmic alternation of the phases of stimulation and depression of electrical activity is disturbed and continuous impulse activity arises in the inspiratory and expiratory nerves and muscles.

In the present investigation the dynamics of the impulse activity in inspiratory and expiratory neurons of the reticular formation of the medulla was studied in hypercapnia and hypocapnia.

EXPERIMENTAL METHOD

Experiments were carried out on 45 cats weighing from 2-3 kg anesthetized with Nembutal (50 mg/kg body weight). Hypercapnia was created by adding 6% CO_2 to the inspired air or oxygen. Hypocapnia was produced by artificial hyperventilation for 5-6 min.

The details of the method are described fully in a previous paper [3].

EXPERIMENTAL RESULTS AND DISCUSSION

Inhalation of air containing 6% CO_2 by the animals for 3-6 min caused an increase in the impulse activity of the inspiratory neurons and depression of the impulse activity of the expiratory neurons of the medulla; the effect reached a maximum after 3-4 min, and then remained constant. The results of experiments in which the impulse activity of a single inspiratory neuron and a group of expiratory neurons was recorded by one microelectrode during hypercapnia are illustrated in Fig. 1. Distinct differences in their responses can be seen. For example, the frequency of impulses in the discharges of the inspiratory neuron increased sharply to reach a maximum at the end of the discharge. This caused an increase in the depth of inspiration and a decrease in the duration of the discharges—to an increase in the rate of respiration. Against this background, the amplitude of the impulses in the grouped discharges of the expiratory neurons was reduced, leading to a decrease in the number of active expiratory neurons.

In the great majority of experiments the changes in impulse activity of the inspiratory and expiratory neurons during hypercapnia were reciprocal in character: the impulse activity of the inspiratory neurons was increased while that of the expiratory neurons was inhibited, just as has been observed in hypoxia. Different changes in the impulse activity of the inspiratory and expiratory neurons during hypercapnia were described by Salmoiraghi and Burns [8, 12]. According to their observations, hypercapnia causes an increase in impulse activity not only in the inspiratory, but also in the expiratory neurons. Changes of this character may be explained by the fact that they cause hypercapnia by adding 7% CO_2 to oxygen and not to atmospheric air. In these conditions two stimuli acted—CO_2 and O_2; the first stimulated impulse activity of the inspiratory neurons, the second that of the expiratory neurons. When the authors repeated experiments as carried out by Salmoiraghi and Burns, they obtained similar results.

Hypocapnia was produced by artificial hyperventilation with air for 5-6 min. In the 2nd minute of hyperventilation the activity of the inspiratory neurons was inhibited. The frequency of impulses in the discharges of the inspiratory neurons fell sharply, and soon the impulses disappeared completely (Fig. 2b). Meanwhile, the impulse activity of the expiratory neurons increased appreciably. As hyperventilation

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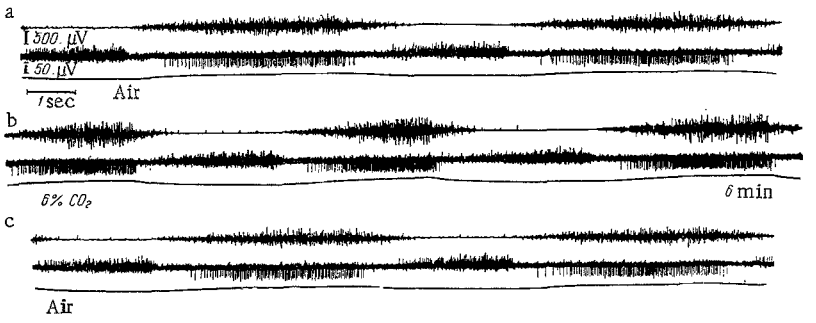

Fig. 1. Impulse activity of a single inspiratory neuron and group of expiratory neurons during hypercapnia. a) Inhalation of atmospheric air; b) inhalation of gas mixture containing 6% CO_2; c) recovery (after inhalation of atmospheric air for 6 min). From top to bottom: EMG of diaphragm muscle, impulse activity of respiratory neurons of medulla, pneumogram.

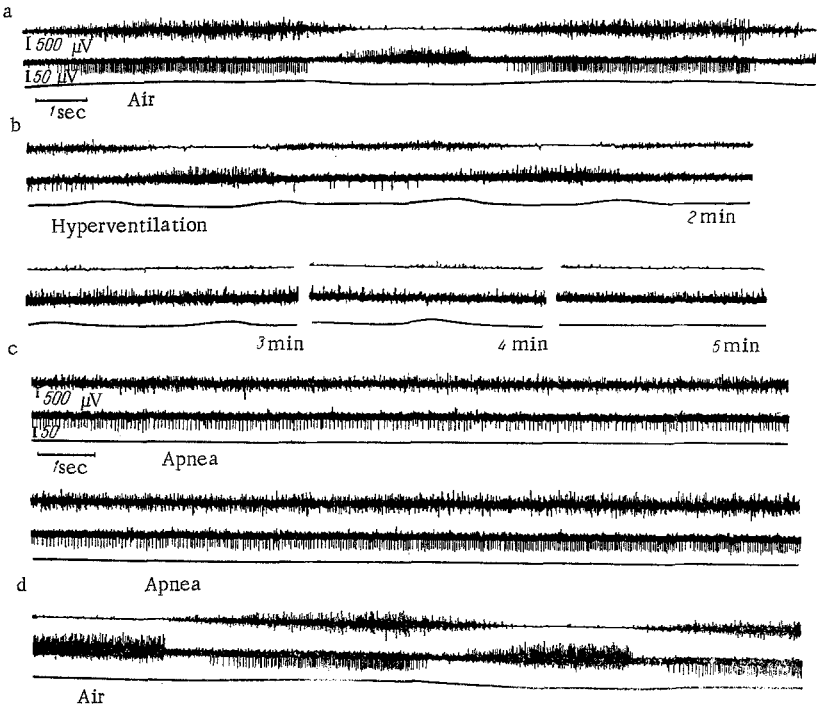

Fig. 2. Impulse activity of a single inspiratory and a group of expiratory neurons during hypocapnia. a) Inhalation of atmospheric air; b) artificial hyperventilation; c) prolonged inspiratory apnea after hyperventilation; d) recovery (after inhalation of atmospheric air for 10 min). Remainder of legend as in Fig. 1.

continued, the rhythmic impulse activity of the expiratory neurons disappeared, and was replaced by continuous activity (Fig. 2b). At the end of hyperventilation (Fig. 2b) the impulse activity gradually diminished and became hardly perceptible. Immediately after the end of hyperventilation, or following a short interval, continuous activity of the inspiratory neurons appeared (Fig. 2c). Meanwhile continuous electrical activity was also recorded in the diaphragm (Fig. 2c). Inspiratory apnea continued for 20, and sometimes for 100 sec. With restoration of rhythmic activity of the respiratory neurons spontaneous respiration was restored.

Salmoiraghi and Burns [8, 12] noted that during apnea the rhythmic activity ceased in some inspiratory neurons and continuous impulse activity developed. In the same conditions, Eyzaguirre and Taylor [10]

recorded continuous impulse activity in the recurrent and phrenic nerves. However, these authors did not attach the proper importance to these facts. Cohen [9], however, who observed this appearance of rhythmic impulse activity and the appearance of continuous activity in the inspiratory neurons during a fall of the alveolar CO_2 concentration in vagotomized cats, put forward the suggestion that CO_2 facilitates periodicity in the working of the respiratory neurons of the medulla and pons. Continuous activity of the inspiratory and expiratory neurons of the medulla was described by Robson and co-workers [11] during respiratory arrest in the phase of inspiration or expiration. They attributed these facts to blocking of the pathways responsible for mutual inhibition of respiratory neurons.

Analysis of the results of these experiments shows that hypocapnia disturbs the rhythmic activity and evokes continuous impulse activity both in inspiratory and expiratory neurons; prolonged and deep hypocapnia depresses the ability of the respiratory neurons to generate impulses. Evidently rhythmic impulse activity is due not only to nervous reflex mechanisms, but also to metabolic processes in which CO_2 plays a decisive role.

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