RELATIONSHIP BETWEEN FREQUENCY AND AMPLITUDE OF MYOCARDIAL CONTRACTIONS IN RATS ADAPTED TO HEAT

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After preliminary adaptation of rats to heat (for 3 h daily at 35°C for 1 month) the amplitude of contractions of the isolated papillary muscles from the left ventricle at 28°C at high frequency was higher than in control animals. This difference persisted at 36°C and disappeared at 25°C. It is postulated that adaptation to heat leaves a definite structural imprint in heart muscle cells.
KEY WORDS: myocardium; relationship between frequency and amplitude of contractions; adaptation to heat; temperature.

In a hot climate the activity of the cardiovascular system of animals and man shows a number of special features. In particular, in the initial period of adaptation considerable tachycardia arises [7, 10]. This adaptive response is evidently due to a change in neuroendocrine influences on the myocardium. However, under the influence of a long-term functional load the possibility of the development of changes in the heart muscle itself cannot be ruled out.

EXPERIMENTAL METHOD

Male albino rats weighing initially 240-270 g were used in the experiments. The rats were adapted to heat for 1 month. For the first 2 weeks the rats were kept in an incubator with self-acting ventilation at a temperature of 35°C for 3 h daily. During the next 2 weeks the exposure of 3 h at 35°C was supplemented by raising the temperature in the chamber to 40°C for 30 min. The weight of the heart and of the papillary muscles did not change as a result of adaptation. The posterior papillary muscle was excised from the left ventricle of the anesthetized rats. The muscles were made to contract in Krebs' solution saturated with carbogen by electrical stimulation under isotonic conditions with a load stretching it at rest. In each experiment the relationship between the frequency and strength of the contractions was studied successively at 28, 25, and 36°C. The initial frequency of contraction was 0.2 Hz. It increased rapidly to 1, 2, and 3 Hz and so on, until the highest reproducible frequency. Each period of increase of frequency was 15 sec. During this time, as the preliminary experiments showed, the amplitude of contraction of the muscle at a given frequency reached a maximum. This method was used because the amplitude of contractions under such conditions was limited by a much lesser degree by the rate of energy formation than if the frequency increased more slowly [1].

EXPERIMENTAL RESULTS AND DISCUSSION

In the control experiments at 28°C an increase in the frequency of contractions led to depression of their amplitude, a fact well known for the rat myocardium [8, 9]. The highest reproducible frequency was 5 Hz. During reproduction of a frequency of 4 Hz (Fig. 1) the amplitude of contraction reached a maximum for that frequency after 10-15 sec, and in the control experiments it averaged 67% of the initial amplitude. The dynamics of the amplitude of contractions of the papillary muscles from the hearts of heat-adapted rats showed a higher rise after the initial fall (Fig. 1). As a result the maximal amplitude of contractions averaged 87% of the initial level and was statistically significantly higher than in the control ($P < 0.05$). This difference was observed not only at a frequency of 4 Hz, but also over almost the whole range of frequencies tested, namely 2 to 5 Hz (Fig. 2)

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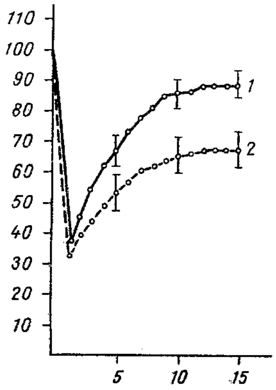

Fig. 1

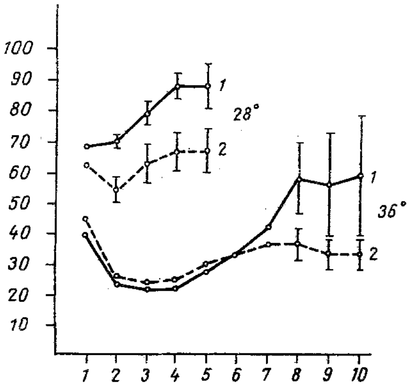

Fig. 2

Fig. 1. Dynamics of amplitude of contraction of papillary muscles with increase in frequency from 0.2 to 4 Hz at 28°C. Abscissa, time (in sec); ordinate, amplitude of contractions (in % of initial, taken as 100) at frequency of 0.2 Hz. 1) Rats adapted to heat; 2) control animals. Values given are M ± 2m.

Fig. 2. Maximal amplitude of contractions of papillary muscles during increase in frequency at 28 and 36°C. Abscissa, frequency of contractions (in Hz); ordinate, maximal amplitude of contractions (in % of initial, taken as 100). Remainder of legend as in Fig. 1.

at a given temperature. With a frequency of 4-5 Hz the amplitude of myocardial contractions of the adapted animals was higher than at a frequency of 2 Hz ($P < 0.05$). In the control this difference was not significant.

At 25°C the amplitude of myocardial contractions of the control and adapted rats was virtually unchanged over a range of frequencies from 1 to 3 Hz and was the same in the animals of both groups. At 36°C (Fig. 2) the decrease in amplitude of the contractions with an increase in frequency up to 3-4 Hz was replaced by an increase at the high frequency. The change of the frequency range within which a difference in amplitude of contraction was observed was connected with a decrease in the highest frequency reproducible by the muscle under the influence of hypothermia. At 28 and 36°C the difference between the myocardium of the control and adapted animals was observed essentially at a frequency close to the highest.

At a frequency of 8-10 Hz the amplitude of contraction of the muscles from the hearts of the adapted animals was on average almost three times greater than the amplitude at 3-4 Hz ($P < 0.05$). In the control animals the increase in amplitude of the contractions did not reach a statistically significant degree.

The myocardium of adapted animals is thus characterized by a smaller depression of the amplitude of contractions at a high frequency than the myocardium of control animals. This could be due to the more efficient energy supply for the contractile function at the higher frequency.

This hypothesis is supported also by the fact that in other types of adaptation – to high-altitude hypoxia [2] and to physical exertion [6] – the analogous increase in the strength of contractions at a high frequency is combined with a proven increase in power of the oxygen transport system and the utilization of energy in the myocardium [3, 4]. Opposite changes are observed in the presence of great hypertrophy of the heart caused by stenosis of the aorta [3, 5].

Another possibility is connected with a change in the system of coupling of excitation with contraction in the myocardial cells as a result of which, in response to a given increase in frequency, a larger number of Ca^{++} ions reacts with the myofibrils.

Whatever its mechanism, the fact that the myocardium of adapted animals can reduce the amplitude of its contractions by a lesser degree as their frequency rises indicates that adaptation to heat leaves a definite structural imprint in the heart muscle.

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EFFECT OF DISTRIBUTION OF FREQUENCY OF STIMULI IN THE VOLLEY ON WORKING HYPEREMIA OF THE GASTROCNEMIUS MUSCLE IN CATS

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The effect of the distribution of frequency of stimuli in the volley on indices of postcontraction hypermia of the gastrocnemius muscle was studied in acute experiments on cats. The introduction of a high initial frequency into the rhythmic volleys was shown to increase the indices of postcontraction hyperemia: the peak blood flow and the supplementary blood volume.

KEY WORDS: gastrocnemius muscle of cats; muscular contraction; postcontraction hyperemia.

The study of postcontraction hyperemia (PCH) in muscles of the human forearm during static and rhythmic exercises has shown that the character of the relationship between the indices of PCH (peak blood flow and supplementary blood volume) and the strength of contraction is the same in both types of exercises [1, 2]. However, after rhythmic contractions with a force of 40-50% of the maximal voluntary effort the values of the peak blood flow and supplementary blood volume were significantly higher than these indices of PCH after static contractions of the same strength. This difference has tentatively been explained [2] by the appearance of a high-frequency burst of discharges of motoneurons at the beginning of each contraction in a rhythmic series [3, 4, 8, 9].

To test this hypothesis the effect of a short high-frequency burst at the beginning of volleys inducing contraction of the gastrocnemius muscle was studied in experiments on cats. It was expected that such a burst would lead (provided that the total number of impulses in each volley remained the same) to an increase in the peak blood flow and the supplementary blood volume.

EXPERIMENTAL METHOD

The hindlimb of anesthetized cats (0.03 g/kg chloralose and 0.5 g/kg urethane) was fixed [6] and the gastrocnemius muscle was mobilized. To record the outflow of blood from the gastrocnemius muscle the popliteal vein (all branches of which except those supplying the gastrocnemius muscle were ligated) was connected to the main trunk probe of an RKÉ-1 electromagnetic flowmeter [7], from which the blood passed through a photo-

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