DIFFERENT RESPONSES OF ANIMALS TO IDENTICAL PHYSICAL LOADS

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UDC 612.766

Gradually increasing and often repeated physical loading, in the form of swimming, when applied to albino rats of the same age, weight, and sex, led in half of the animals to adaptation to this loading, but in the other half of the animals to a very rapid collapse of compensation, as shown by disturbance of the function of the central nervous system, hypoxia, disturbance of glycogen utilization during work, a decrease in the rate of gain of body weight, and hypertrophy of the myocardium.

The action of prolonged, regularly repeated physical exertion on man or animals has been studied usually by comparing groups of trained and untrained subjects [5, 6, 8, 9, 16]. However, such comparisons must be made with considerable care, for the result of prolonged muscle activity is not always the same.

The object of the investigation described below was to study the character of individual variations in morphological changes arising in response to repeated physical loading.

EXPERIMENTAL METHOD

Experiments were carried out on 47 noninbred male albino rats taken from the same litter and weighing 170-180 g at the beginning of the experiment. The animals were tagged, and weighed every 10 days throughout the experiment. The experimental rats (35) were made to swim 6 times a week in the mornings before feeding, for periods starting from 10 and increasing to 60 min, in a large bath containing water heated to 35-36°C; 12 rats acted as controls. All the animals were sacrificed after 1 and 3 months. On the day of sacrifice, several animals from the control group, which had been left in the water for the same length of time as the experimental animals on that day, were added to rats which had swum for a long period. The rats were sacrificed in groups immediately after removal from the water, or after periods of 1 and 3 h and 1, 3, and 6 days. The heart and liver were weighed; pieces from these organs were fixed in Carnoy's fluid and embedded in paraffin wax; sections were stained with hematoxylin-eosin and by Shabadash's method, with a salivary amylase control.

TABLE 1. Ratios of Weights of Heart and Liver to Body Weight of Rats

Group of animals	Ratio of weight of organs to body weight (in %)	
	heart	liver
Trained	0.47 (0.35-0.62)	4.1 (3.1-4.6)
Overtrained	0.62 (0.52-0.83)	4.2 (3.2-4.8)
Control	0.48 (0.40-0.65)	3.9 (3.2-0.7)

Department of Anatomy, P. F. Lesgaft Institute of Physical Culture. (Presented by Academician of the Academy of Medical Sciences of the USSR S. A.Sarkisov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 69, No. 6, pp. 29-33, June, 1970. Original article submitted October 9, 1969.

TABLE 2. Dynamics of Utilization and Regeneration of Glycogen in Rat Liver

Group of animals	Time of sacrifice after exertion					
	h			days		
	0	1	3	1	3	6
Trained	++	++++	++	+++	+++	+++
Overtrained	+++++	++	+	++	+++	++++
After swimming once	—	+	+	+++	+++	+++
Control without swimming	+++	+++	++	+++	+++	+++

TABLE 3. Dynamics of Utilization and Regeneration of Glycogen in Rat Myocardium

Group of animals	Time of sacrifice after exertion					
	h			days		
	0	1	3	1	3	6
Trained	++	+++	++++	+	+	+
Overtrained	++++	+	++++	+++	++	+
After swimming once	—	+	++++	+	+	+
Control without swimming	+	+	++	+	+	+

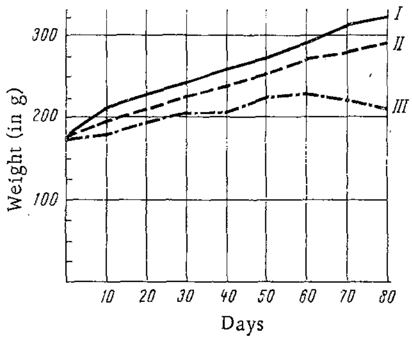

Fig. 1. Dynamics of body weight of rats. I) Control animals; II) trained; III) overtrained animals.

EXPERIMENTAL RESULTS

Swimming was accompanied by some increase in the respiration and heart rates, by increased pigmentation of the iris, and increased reflection from the fundus oculi. In the third week of the experiment, when the rats were staying 15-20 min in the water, pallor of the iris, constriction of the pupil, exophthalmos, and the appearance of brown circles around the eyes were observed in individual rats. After removal from the water these rats were extremely restless and excited. Toward the middle of the second month, when the animals were swimming for 25-30 min, these phenomena were observed in approximately one-third of the animals, while toward the beginning of the third month, when physical exercise continued for 40-45 min, it was found in almost half of the animals. With an increase in the duration of swimming the intensity and duration of the period of excitation increased from 3-5 to 7-10 min. All the rats of this group showed a small increase in weight (Fig. 1), and from the beginning of the third month the body weight actually showed a tendency to decrease.

The other half of the animals, exposed to the same physical loading, tolerated it perfectly easily. Signs of hypoxia and restless movements were observed extremely rarely, and were of very short duration. Usually the rats shook themselves quietly after removal from the water, and immediately began to eat. Their increase in weight was almost the same as that of animals of the control group (Fig. 1).

To use the accepted terminology [2, 4], the first group of swimming animals was described as overtrained, and the second group as trained.

In animals of both these groups sacrificed after one month, no significant abnormalities were found at autopsy. In the retrained rats sacrificed during the first few hours after swimming for 3 months, marked congestion of the organs, dilatation of the chambers of the heart, flabbiness of the walls of the heart (by the beginning of the first day these features had disappeared), and a significant ($P < 0.05$) increase in size of the heart but no statistically significant difference in the weight of the liver were observed (Table 1). The external appearance, and the size and weight of the heart and liver were extremely similar in the normally trained rats and the rats of the control group.

Microscopic examination of the hearts of the overtrained rats sacrificed after three months revealed focal hypertrophy of muscle fibers with an increase in the size of their nuclei in the inner layers of the ventricular wall.

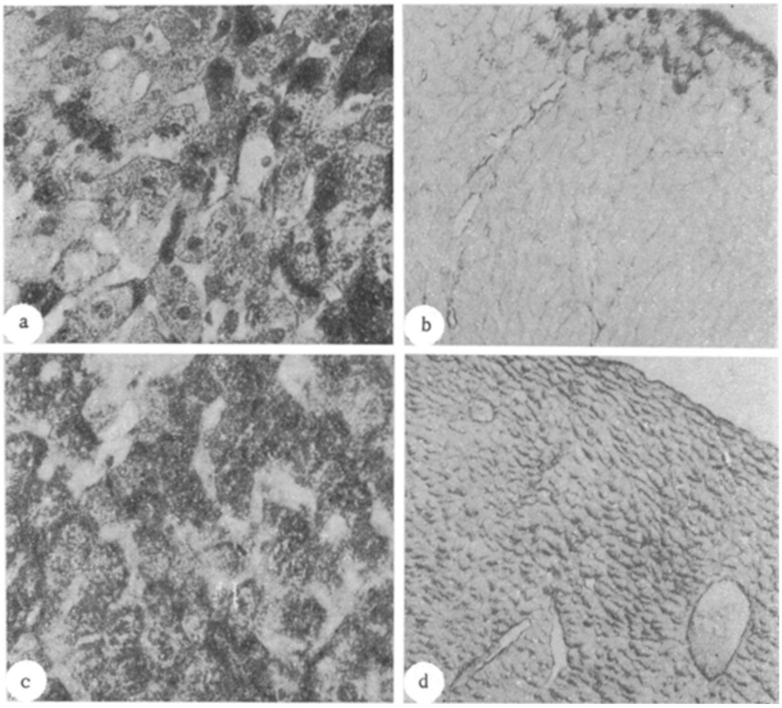

Fig. 2. Glycogen content in liver and heart muscle of rats sacrificed immediately after removal from water (stained by Shabadash's method). Normally trained rat: a) glycogen granules fill only parts of the liver cells (420 ×); b) only cells of outer layer are saturated with glycogen in the myocardium (120 ×). Overtrained rat: c) all liver cells are saturated with glycogen granules (420 ×); d) cells of all layers of the myocardium are filled with numerous glycogen granules (120 ×).

Glycogen is a very important energy-producing and plastic material in the body [5, 7, 9]; the dynamics of utilization and regeneration of glycogen in the heart muscle provides a criterion of the state of training [1, 9, 14, 15].

Observations made in this investigation showed that differences between the utilization and regeneration of glycogen reserves in normally trained rats and overtrained animals appeared after one month and subsequently were maintained. The glycogen content in the liver and heart muscle cells was assessed by a five-point system (–, +, ++, +++, ++++). Results showing the dynamics of utilization and regeneration of glycogen by the organs are given in Tables 2 and 3.

Animals exposed for the first time to physical exertion by swimming for 25-60 min completely utilized their glycogen reserves stored in the liver and myocardium in the course of the work. Gradual restoration of the glycogen reserves began immediately after the work had ended and reached normal values (after passing through a phase of oversaturation in the heart) by the beginning of the first day.

Normally trained rats, adapted to this type of work, utilized only part of their glycogen reserves in its performance: glycogen was preserved in many liver cells (Fig. 2a), and in the inner and outer layers of the myocardium (Fig. 2b). Restoration of the glycogen content in these organs took place more rapidly in normally trained rats than in untrained animals. After one hour, both the liver and heart muscle were overfilled with glycogen granules, and in the heart this state continued somewhat longer than in the liver.

The development of features of overtraining was resected very quickly in disturbances of glycogen utilization. In rats of this group sacrificed after one and three months, neither the liver nor heart muscle utilized its glycogen during the work (Fig. 2c, d). Such a paradoxical reaction with blocking of the glycogen was most probably due to hypoxia [3, 11], for after the end of the work, and liquidation of the oxygen debt, rapid utilization of glycogen began; this state in the heart was soon replaced by a phase of oversaturation, which lasted until the beginning of the third day; in the liver some degree of glycogen deficiency was still observed after 24 h.

Such a marked contrast in the effect produced by exposure of similar animals to the same stimulus can be attributed to differences in their ability to regenerate the structures damaged during physical exertion, such injuries involving not only the working organ, but also, and indeed, primarily cells of the central nervous system [10, 12, 13]. Under such conditions, some rats responded adequately to physical loading, because it matched the rhythm of their compensatory and adaptive processes and led to the development of adaptation to this type of muscular activity. With the other group of animals, in which the cycle of changes was less marked, the same motor activity very quickly became excessive and led to a collapse of compensation, revealed by disturbances of the function of the central nervous system, hypoxia, disturbance of the utilization of glycogen during work, slowing of the rate of increase of body weight, and hypertrophy of the myocardium.

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