Effects of Endurance Training on Tolerance to Cold in Rats

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Abstract

Cold acclimation in rats is largely a metabolic process. Also the capacity for elevating the metabolic rate is increased by physical training. The present study was disigned to explore whether exercise would confer greater tolerance to cold. Three groups of 10 male rats were kept for 5 weeks under the following conditions; warm environment (23 ℃), untrained (Warm); Cold environment (5 ℃), untrained (Cold), warm environment (23 ℃), physical training (Trained). The trained group underwent treadmill exercise. The cold adaptation and physical training demonstrated by differences ($p<0.01$) in resting metabolic rates between the warm and cold or trained groups. Exposed at 5℃, the average metabolic responses was; for warm, 38.01± 3.66 ml/kg/min; cold, 43.45 ± 4.15; trained, 45.99 ± 3.07; the differences between warm and cold or warm and trained being significant ($p< 0.01$). The increase of metabolic responses to 0.4 mg/kg ip. noradrenaline injection were respectively; 5.39 ± 2.66 ml/kg/min, 11.43 ± 4.15, 0.13 ± 5.44. It suggested that the elevated metabolic response to cold in trained group was mainly due to an improved shivering capacity.

ラットの耐寒性に対する持久的トレーニングの影響

ラットにおいて寒冷適応は，代謝量の増大を生じる。また，その代謝量の増大の能力は，トレーニングによって改善される。本研究は，トレーニングが耐寒性を増大させるかどうかを検討することにある。それぞれ雄ラット10匹ずつの3グループは，5週間下記の条件で飼育した。(1)温暖対照：23± 1℃，非運動鍛練，(2)寒冷馴化群：5°±0.5℃，非運動鍛練，(3)運動鍛練群：23± 1℃，持久的運動鍛練。

安静時代謝量（23℃）は，温暖対照群と寒冷馴化および運動鍛練群の間に有意差（$p < 0.01$)が認められた。5℃の寒冷曝露時，平均代謝量は，対照群 38.01 ± 3.66 ml/ kg/min，寒冷群 43.15± 4.15，運動群 45.99 ± 3.07 であり，対照群と寒冷群，対照群と運動群の間にはそれぞれ有意差（$p < 0.01$）があった。

Noradrenaline 腹腔内投与 0.4 mg/kg における代謝の増加反応は，それぞれ対照群 5.39 ± 2.66 ml/kg/min，寒冷群 11.43 ± 4.15，運動群 0.13 ± 5.44，であった。運動群における寒冷曝露による代謝反応は，主にふるえ産熱の改善によることを示した。

It is generally accepted that cold acclimation in small manmals, such as the whites rat, is largely a metabolic process giving the animal a greater capability to produce heat.

As the exposure becomes prolonged, the heat production remains elvated but the shivering declines and eventually disappears (1). In its place, heat production is maintained by non-shivering thermogenesis (2).

Evidence for participation of striated muscles (3) and brown adipose tissue (4) in non-shivering thermogenesis has been abtained. The increase in thermogenic capacity of brown adipose tissue during cold acclimation has been attributed to heat generated in the process of triglyceride lipolysis to FFA, and glycerol and the fatty acid synthesis-oxidation cycle (5).

Furthermore, cold-acclimated rats have an increased metabolic and thermal response to the sympathetic hormone, noradrenaline, which is known to promote FFA mobilazation (6).

The capacity to increase the metabolic rate and, heace, of producing heat is also improved by prolonged physical training. The development of greater metabolic capacity is associated with increased muscle mass and myogrobin contents, improved vascularization, and larger blood volume, all factors being important in relation to cold tolerance (7,8).

A relationships between physical fitness and the ability to resist cold has been demonstrated in humans (9). In view of the successful demonstrations of metabolic acclimation to cold in small manmals, it seemed pertinent to examine the possibility that physical training alone will confer an improved tolerance to cold in the rat, and to test whether or not physical training will improve the ability to resist cold.

Methods

The experiment was carried out with 30 male Wistar rats. All the rats were received at the age of 5 weeks, initially weighting 100–110g each. The rats were distributed into three groups of ten rats so that each group had about the same average body weight. Body weight were recorded to the nearest gram, one time per week, at about the same afternoon hour.

The three groups were kept for 5 weeks under the following conditions; Group Warm (W). This was the control group. The rats lived in a neutral environment (23±2℃) in cages. This rats were considered to be physically inactive. Group Trained (T). These rats also lived in a neutral environment, but this group was subjected to forced physical training on a treadmill, the variable speed control system permitted belt speeds to be varied from 20 to 30 m/min. Adjustable front legs allowed the treadmill to be inclined to 8°. Group Cold (C). This group was maintained physical inactive, but the rats were chronically exposed to an ambient temperature of 4.0±0.5℃ in an environmental chamber.

The rats were given a prelininary period of 3 days, with sevaral daily, short–term (5 min) running periods to accustom thermselves to the treadmill. After that they underwent a progressively increasing physical–training program, exercising once daily, five times per week. The total distance traversed each week on the treadmill during the forced training program is indicated in Fig. 1. At the end of the training period the rats were capable of continuously running for 1 hr at 30 m/min on a 8 grade.

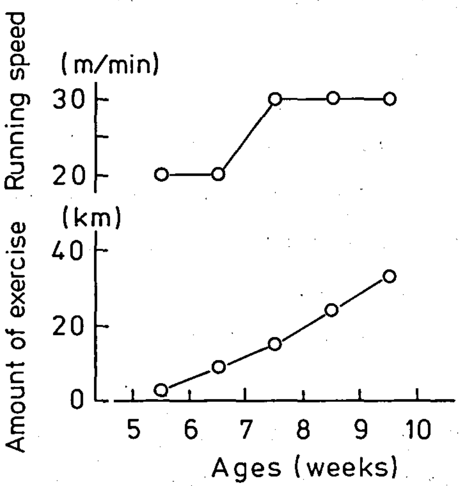

Fig. 1 Training program.

As described, the rats were accustomed to rest patiently in a small metabolism chamber while subjected to the low noise from an air pump. The metabolic rate was obtained indirectly by measuring the rate of oxygen consumption and carbon dioxide production using an open-circuit method.

The rats were tested in two environments, 4℃ and 24℃, the temperatures being measured inside the metabolism chamber. During these tests the two chambers were placed in a small environmental chamber constructed of expanded polystyrene foam with cold air circulating through it. Periods of activity occurred mainly during the first 20 min after the rat had been exposed to cold. After this time they would reduce their body surface area by trucking the legs and assuming a ball-like position with the tail underneath themselve for the rest of the 1-hr test period.

The resting metabolic rate was obtained while the rats were resting quietly at a temperature of 24℃. After the complete resting metabolic run of 1 hr, the rats received a intraperitoneal injection of a 0.4 mg/kg dose fo 1-nonadrenaline bitartrate (NA). Since some of the rats were restless during the first 0-5 min after the injection of noradrenaline, the average increase in oxygen consumption from the 5 th to the 20 th min was considered as being the metabolic response to noradrenaline.

The rectal temperature was measured at the begining and after conclusion of each metabolic run. A rapid-responding thermometer was inserted 5 cm into the rectum and the temperature recorded to the nearest 0.1℃.

In addition to assessing the metabolic response to NA, a temperature test was accomplished to study the alterations of rectal temperature during the first 20 min after intraperitoneal injection of NA. Measurements of the rectal temperature were taken at short times before and after NA injection.

Results

Effect of Chronic Cold Exposure and Physical Training on Body Gowth

The changes in average body weight for the three different groups are given in Fig. 2. The wieght curves of the three groups, W, C and T were separable at the end of 5 weeks. Three was a significant difference ($p < 0.01$) in mean body weight between group W and group C or T, and between group C and group T.

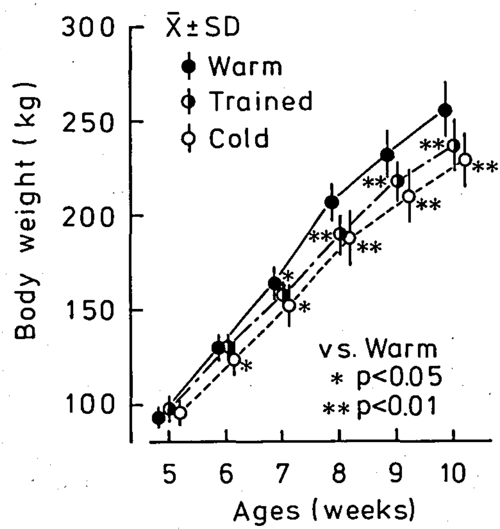

Fig. 2 Changes in mean body weight in three groups.

Metabolic and Thermal Measurements

The metabolic rates at three different ambient temperatures are given in Fig. 3. Cold acclimation was demonstrated by a significant difference ($p < 0.01$) in resting metabolic rate between the group W and the group

C. Also, a significant differnce was found between group W and group T. The average resting metabolic rates (expressed in ml 0_2/kg/min ± SD) for groups W, C and T were, respectively, 18.43±1.22, 22.02± 1.46, and 22.60±1.29.

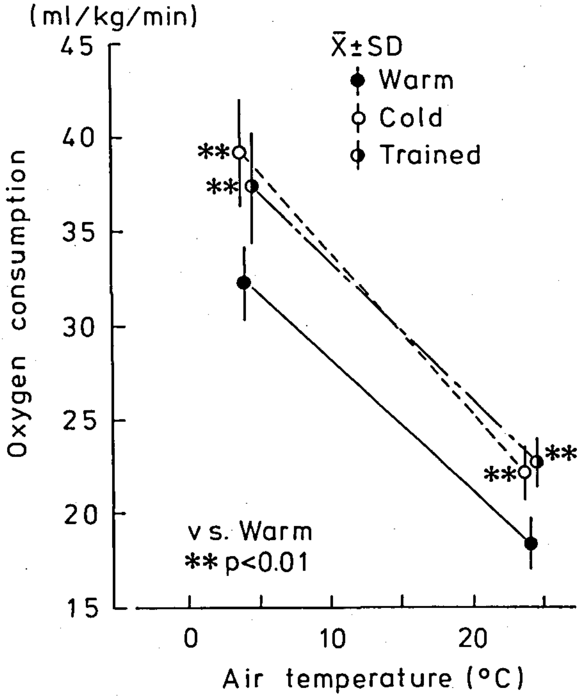

Fig. 3 Resting metabolic rates at 24℃ and metabolic responses to cold environment.

Tested at 4℃, the average metabolic response in ml 0_2/kg/min ±SD was: for warm 32.26±2.04; 39.10±2.85; and for trained, 37.47±3.15, the difference between group W and group C or T being significant ($p<0.01$). Thus, the physically fit rats in group T were capble of increasing their heat production during cold exposure to a considerable higher level than rats in group W. But the different between group C and group T was not significant.

It should be noted that the rectal temperature was measured at the begining and conclusion of each metabolic run in the cold environments.

Cold exposure tested at 4℃, the average rectal temperature were for group W; 37.33±0.34℃, group C; 38.49±0.22℃, and group T; 37.83±0.31℃. The difference between group W and group C or group T were significant.

The metabolic responses to a intraperitoneal injection of a 0.4 mg/kg dose of l–noradrenaline bitartrate is demonstrated in Fig. 4. The average values give in ml O_2/kg/min ± SD were, respectively, for group W, C and T, 5.39±2.66, 11.43±4.15, 0.13±5.44. The difference between

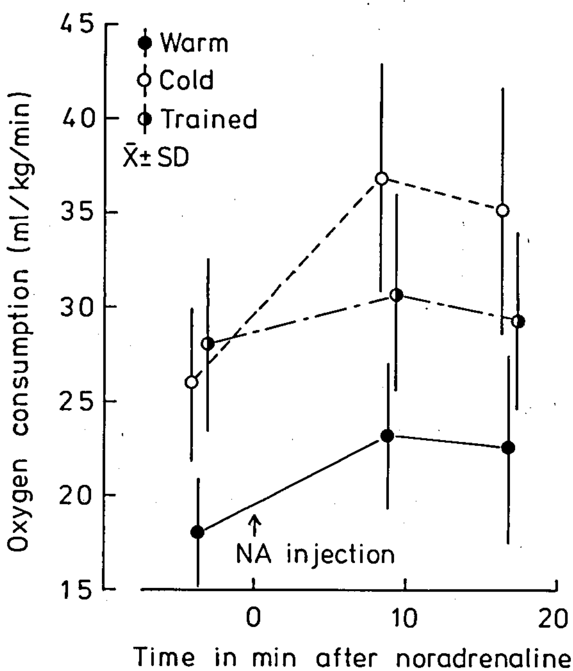

Fig. 4 Metabolic responses to noradrenaline measured from 5th to 20th min after injection in three groups.

the thermonutral group (warm) and the cold-acclimated group were significant ($p < 0.01$).

The alternations in rectal temperature during the first 20 min after a 0.4 mg/kg noradrenaline injection are shown in Fig. 5 , there was a well-difined separation between the temperature curves of the cold-acclimated rats, the thermonutral control rats and the thermonutral trained rats during the first 20 min after injection of noradrenaline ($p < 0.05$).

Group T was least responsive, but at no time that the temperature were significantly separable from that of group W.

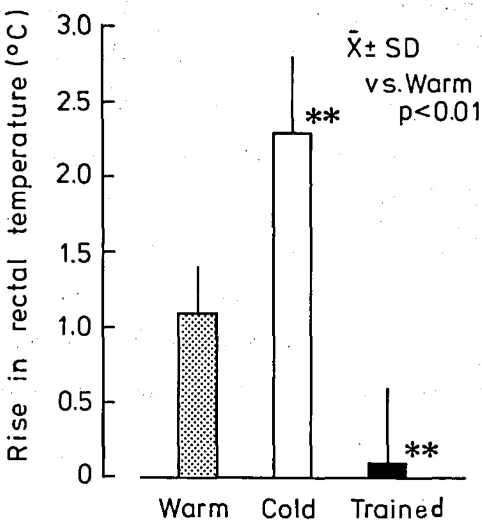

Fig. 5 Thermal responses to NA as measured by the rectal temperatures.

Discussion

Physical Training and Cold Acclimation as related to Body Growth

Prolonged physical training of rats is associated with improved body growth in terms of an increase in the weight of muscles, bones and most internal organs (10), but the body weight gain is somewhat masked by a loss of fat when compared to a population of untrained rats. This is demonstrated in Fig. 2. where the sedentary rats in group W show a considerably greater whole–body growth rate than the physically trained rats. The latter accumulated minimal amouts of fat in comparison to the large fat deposits grossly observed in the inactive rats after termination of the subjects.

Chronic exposure to low environmental temperatures inhabits the body growth as a whole, although the cold exposed rats are consuming a substantially greater quantity of food than the control.

According to Heroux and Gridgemar (11), the effects of sustained cold differ within the organism. In rat, there is an atrophying influence on the skeletal muscles, bones, subcutanous fat masses, spleen, and thymus, while the heart, liver, kidneys, thyroid, adrenals, and digestive tract undergo hypertrophy (11).

Cold–acclimated rats have a smaller body weight than the W of the same age mainly because they have a smaller muscle mass. Fat reserves are also reduced, the decrease accounting for about 30 % of the total body weight difference (12).

Metabolism and Tolerance to Cold

The metabolic measurements reveal that prolonged physical training alone induces a greater tolerance to cold in an increased capacity to elevate the metabolic rate (13). Fig. 3 shows that the physically fit rats (trained) at low ambient temperature were capable of increasing their heat production to a considerably higher level than the rats in W group. The metabolic responses of group trained in the 4 ℃ test environment were about 16 % greater than the responses of group W. Cold acclimation declines to enhance the ability to tolerate cold more than does physical training.

Noradrenaline released from sympathetic nerve ending is probably the most important mediator of the metabolic response to cold in cold acclimated rats (6, 14). Therefore, the metabolic and thermal responses to the hormone were tested in all three groups of rats to determine if there was any similarity in these responses between cold-acclimated and physically trained rats.

The data given in Fig. 4 and 5 show that increased sensitivity to the calorigenic action of noradrenaline is a feature of cold acclimation and cannot be used to explain the improved metabolic response to cold in physically fit rats (13). As seen in Fig. 4 and 5, there is a significant difference between group W and group C, group C exhibit a considerably higher response. It shoud be noted that Fig. 4 and 5 represent the average metabolic and thermal, respectively, responses to noradrenaline measured from the 20 th min after injection. The calorigenic action of noradrenaline in cold-acclimated rats is characterized by an immediate and pronounced rise in oxygen consumption and body temperature after the injection of the hormone into the animal.

Brown adipose tissue increases in mass and thermogenic capacity during cold acclimation (4). At the extermination of the subjects in the present investigation, a gross comparison of the interscapular brown fat pads was made between the different groups. Thus, these observations are in accordance with the metabolic responses to noradrenaline in the different groups.

Besides behavioral regulation, muscular activity in terms of increase muscular tone and shivering, is the immediate response to cold in the non-acclimated animal. Since some 50 % of the total body weight of a rat is muscular tissue (15), the total contribution of the muscle mass to the resting metabolic rate, as well as to the cold-induced elevation, is not inconsiderable. Since the size, vascularization, and myoglobin content of muscles, and hence their ability to absorb and utilize oxygen during rest and exercise, is increased by physical training, the maximum heat production of a physically fit organism is grater than the untained one. It is, therefore, quite probable that the improved capacity to elevate the metabolic rate in the cold, observed in the non-acclimated physical fit rats is due to an improved shivering capacity attributable to a relatively larger and better vascularized muscle mass.

It would be an aversimplification to consider the muscle mass alone responsible for the augmented heat production found during cold exposure in physically trained rats. Jansky (16) has suggested the existence of a nonshivering thermogenesis location to cold acclimation. Several investigators have reported an enlargement of the liver after prolonged muscular exercise (10), it is tenable that the liver may contribute to the cold-induced heat production at an enhanced rate in physically well-trained animals as compared to the warm controls.

Presumably, other organs and tissues may have similar potent heat production capacities. It was somewhat surprising to find tha physical training apparently did not further improve the tolerance to cold in the cold-acclimated rats. There is a probability that the small, but consistent, difference noted at the lowest ambient test temperature would have been magnified if the animal had been tested during exposure to cold. In other wards, an additional effect of physical training could perhaps have been revealed where the rats had to rely upon both the cold-induced nonshivering thermogenesis and a possible improved shivering capacity (13).

In summary, the results of this investigation suggest that prolonged physical training confers an improved tolerance to cold in rats.

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