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Is Cold Acclimatization Necessary for Mammalian Hibernation[1]

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Abstract. (1) In this study hibernator rodents were exposed to a warm environment and then a cold environment to determine whether cold acclimatization is necessary to permit a hibernator to go into dormancy. Four species were tested in September: hedgehogs, woodchucks, Glis dormice, and Eliomys dormice. With three species, (hedgehog, woodchuck, Eliomys dormice) if the rodents went into hibernation at all, they were capable of doing this within 24 to 48 hours after being removed from a warm environment. (2) Those individuals which hibernated directly after being placed in a cold environment, had not shown thermal lability in the warm environment. (3) One species (Glis dormice) seemed to require at least 10 days of cold preconditioning before it entered the state of hibernation. (4) We conclude that cold acclimatization is not necessarily required in preparation for the dormancy of mammalian hibernation. (5) With one specimen (woodchuck) which was monitored in detail, all initial hibernation occurred during the usual time of sleeping. (6) One specimen (woodchuck) was monitored all winter while hibernating in a free environment. During changes in the winter air temperature, the heart rates showed a precise inverse and homeostatic relationship with air temperature during hibernation, unrelated to awakening from hibernation. Therefore, hibernation in the free environment with a variable air temperature must be a more variable process than in the constant-temperature cold room.

When rodents are first exposed to continuous cold, physiological mechanisms for combating cold gradually change over at least a 10 day period (Folk, 1966). The basal metabolic rate increases, a higher maximum metabolic rate is observed, non-hivering thermogenesis increases, shivering decreases, and there is hypertrophy of endocrine glands and of visceral organs. The present study concerned whether these physiological changes called cold acclimatization are necessary before a mammalian hibernator may go into dormancy.

Methods

Four species of hibernators were tested in September: three female hedgehogs (Erinaceus europaeus); three female woodchucks (Marmota monax); four edible dormice (two female) (*Glis glis*); and four garden dormice (two female) (*Eliomys quercinus*). The cold room (hibernation) phase of the study was terminated after

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four weeks except with one monax which was studied for two winters. Two of the hedgehogs and two of the woodchucks did not hibernate within the first three weeks. Later it was learned that if food and water had been removed, it might have induced these animals to hibernation. All dormice did hibernate within the one month coldroom period. The following physiological conditions were monitored with the rodents in a warm room, and then a cold room, without restraint: skin temperature by recording radiometer, body temperature and heart rate-EKG by the Iowa implantable radio-capsule (Folk, 1964). One of the woodchucks which did hibernate contained an 8 gram radio-capsule which gave good physiological data for two years with one winter in a cold room and the second winter outdoors. For this second winter the animal was established for hibernation in a large outdoor cage with abundant insulation and an opportunity to burrow in dirt and shredded newspaper. The cage was covered with heavy canvas. It may be that this is the first mammal to be studied by physiological radio-capsule while hibernating in a natural burrow in an outdoor environment.

The studies on the hedgehog and the two winters of study of the woodchuck depended mostly on heart rate and EKG measurements. However, body temperature was monitored during the second winter of hibernation in the woodchuck by means of radio detuning. A constant body temperature was known to occur in this individual in hibernation in spite of a variable air temperature because there was no essential frequency change of the temperature sensitive heart radio-capsule. Heart rates were continuously monitored by automatic recording for 30 seconds each half hour at all times (Folk, 1964). There were two exceptions, when specimens were moved to the cold room; on both of these occasions 24 hours of recording was lost because of mechanical failure of equipment.

All dormice were monitored only by body temperature techniques. Two of them contained body temperature radio-capsules (one Glis and one Eliomys). A change in skin temperature in both the warm and the cold environment was monitored by recording radiometer.

Results

Three of the species went into hibernation within 24 to 48 hours after being moved from the warm environment. One species seemed to require at least 10 days of cold preconditioning. The details are as follows:

Hedgehog: Two specimens did not go into hibernation. The specimen which hibernated had been maintained for three months after surgical implantation. Its steady weight gain, avid appetite, and vigorous behavior indicated good health. During the control

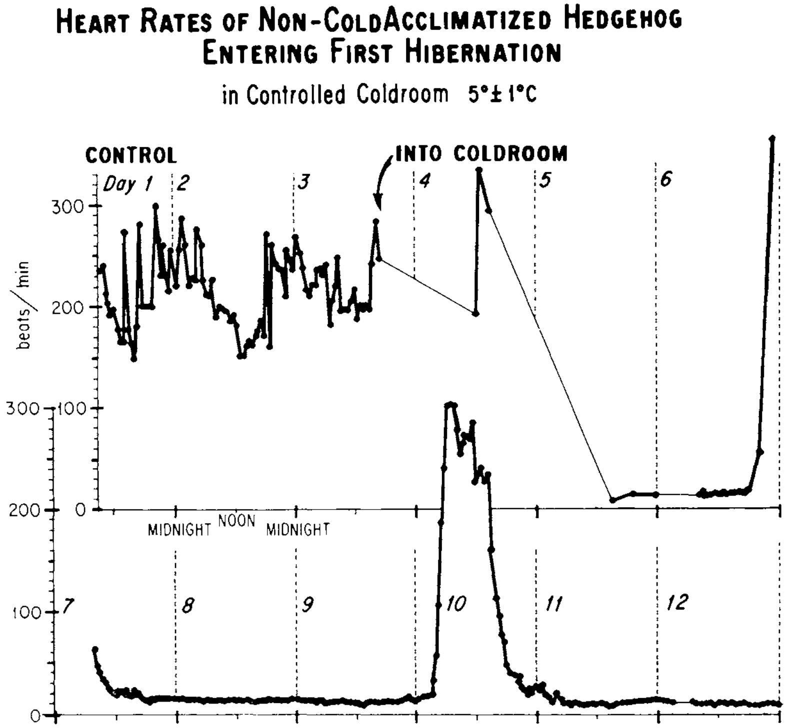


Fig. 1. Heart rates of non cold-acclimatized hedgehog entering first hibernation in a controlled cold room (5 ± 1°C).

period just before exposure to cold, sleeping and active heart rates were nearly identical to those which had been recorded from August 6 up to time of cold exposure (Fig. 1). The ten highest heart rates during the summer varied from 273 to 320 beats per minute, usually occurring between 8:00 a.m. and 10:00 a.m. The ten lowest heat rates, which usually occurred during sleep, varied from 120 to 136 beats per minute. Since these summer heart rates were maintained up to cold-exposure then undoubtedly the animal was *not* experiencing a preliminary or partial state of lethargy in which it lowered its body temperature toward the air temperature of the room (26.5°C, RH 60%). The next procedure was to remove the animal cage to the cold room. In this case as in the rest of the experiment, the question was whether the animal could go into hibernation within one or two days or would require 10 days or more during which time the mechanisms of cold acclimatization would be induced (Folk, 1966). Due to mechanical failure the animal was not recorded the first day but hand readings indicated that its heart rate was very high during the twelfth hour after exposure to cold (Fig. 1). By the 24th hour the animal was in deep hibernation with a heart rate of 9-13 beats per minute. The preliminary bouts of hibernation (the first 10 days) were short, but this is characteristic of all mammalian hibernators (Folk, 1966).

Woodchuck: The first winter of hibernation, food and water were not removed, as it should have been and the animal did not hibernate until four weeks of cold exposure in the coldroom. After this the animal showed typical bouts of hibernation (Fig. 2). The level of hibernating heart rates may be compared with the hibernating heart rates the animal displayed its second year in the outdoor environment (Fig. 3). Four bouts of awakening (Fig. 2) are compared to show the length of time awake and the abrupt massive increase in metabolic rate which is, of course, accompanied by an extremely rapid change in heart rate. The gradual return to the condition of dormancy is evident. In September of the second year the experiment was repeated except that the animal was removed

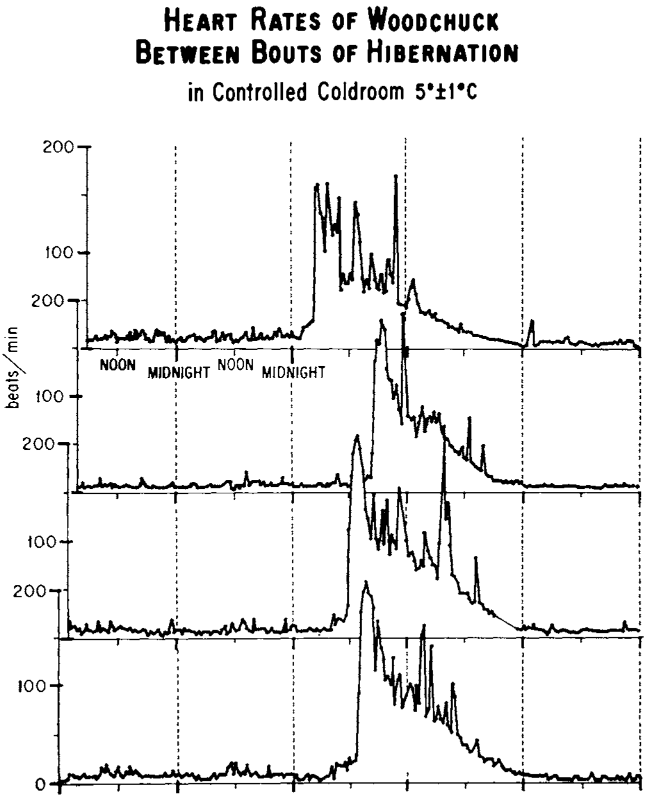


Fig. 2. Heart rates of woodchuck awakening from bouts of hibernation in controlled cold room (5 ± 1°C) (first winter).

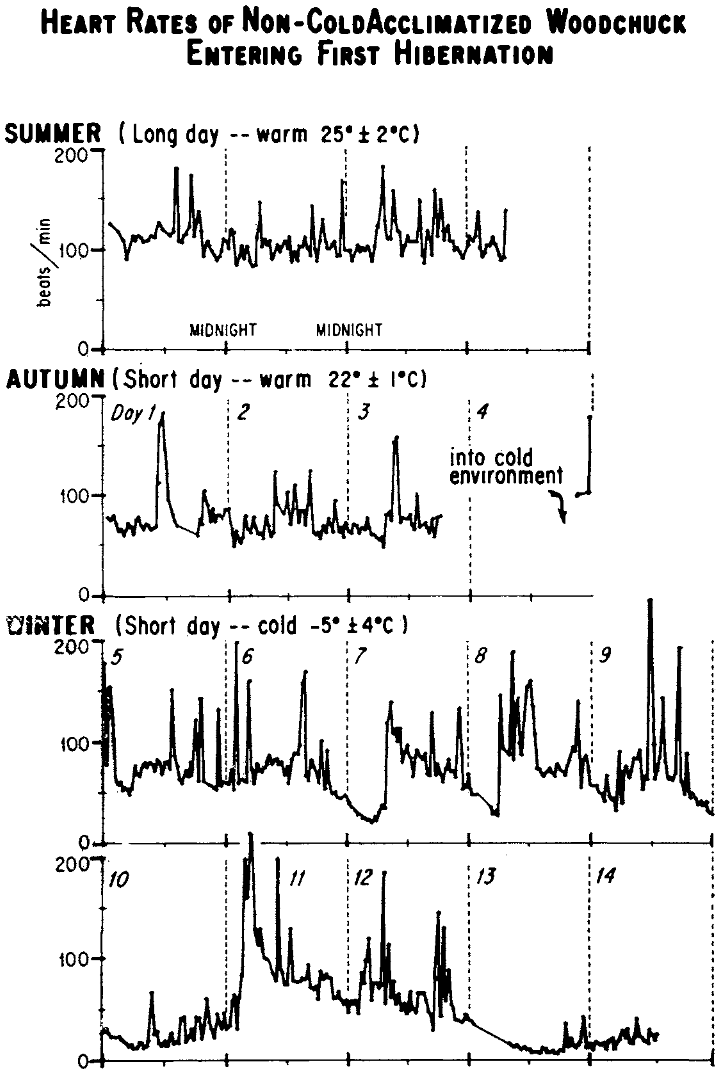
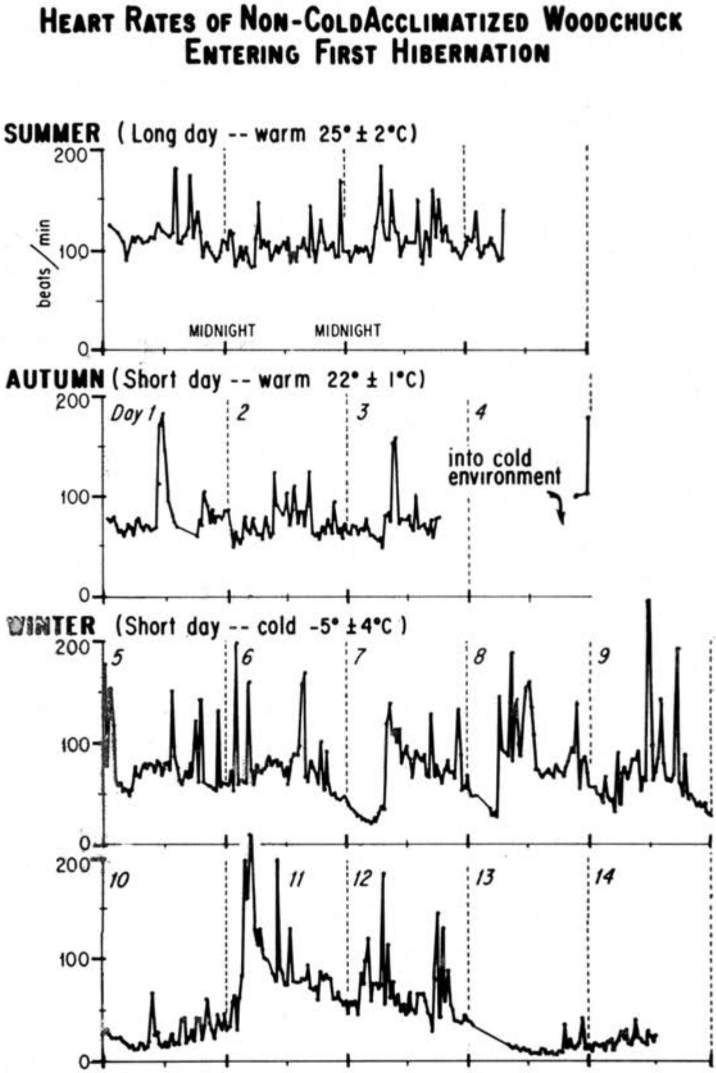


Fig. 3. Heart rates of non cold-acclimatized woodchuck entering first hibernation in the outdoor environment. Control heart rates for summer and autumn are presented in lines 1 and 2.

from the warm environment to the outdoor cold environment. The sleeping heart rate was high during the summer (80-90 b/m). During the fall the animal added a great deal of weight and undoubtedly the short photoperiod prepared the animal for hibernation although this preparation cannot be called cold-acclimatiza-



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from the warm environment to the outdoor cold environment. The sleeping heart rate was high during the summer (80-90 b/m). During the fall the animal added a great deal of weight and undoubtedly the short photoperiod prepared the animal for hibernation although this preparation cannot be called cold-acclimatization. The sleeping heart rate was lowered to 50 beats per minute. This physiological procedure had not occurred with the hedgehog. When the woodchuck was exposed to cold in the outdoor environment, it dug a burrow in deep insulation. After 48 hours, the animal entered the hibernating state with a heart rate of 10 beats per minute for approximately 8 hours, followed by a normothermic state, followed quickly by two more bouts of hibernation. These results might be called test drops into hibernation but it is evident that the usual changes which we call cold-acclimatization could not have been completed in this short period of time. These test drops have been observed before, but they took longer; Strumwasser (1959) describes test drops in body temperature requiring two days per drop and taking six days to enter hiberation. However, his animals were cold-acclimatized before they entered hibernation. Our data under discussion is unusual because the observa-

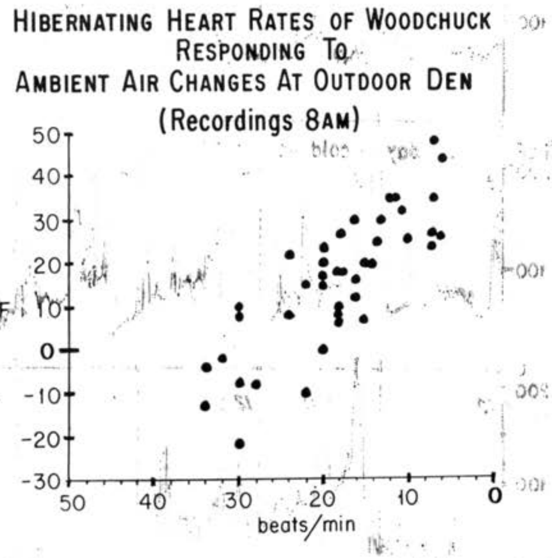

Fig. 4. Heart rates and air temperatures over burrow of woodchuck hibernating in the free environment. The 8:00 a.m. hibernating heart rates for all winter are shown except those within 24 hours of awakening from hibernation.

tions were monitored while the animal was in the outdoor environment under variable air conditions and yet qualitatively the animal displayed typical hibernation of the sort which it experienced the winter before. Quantitatively, the type of hibernation is undoubtedly more typical of animals in the free environment; a remarkable case of homeostasis was displayed as the animal in hibernation responded to changes in the winter air temperature (Fig. 4). Although we were unable to monitor the deep burrow temperature or the fur of the animal, systematic changes were observed related to air temperature over the burrow. We have plotted Series A: only the hibernating heart rates at 8 a.m. each morning and only those which occurred removed in time from the awakening process by approximately one day. During this steady state of hibernation the body temperature showed little variation, probably no more than 1°C. This exact variation can only be determined after the radio is removed from the animal. The method of monitoring temperature is to observe the frequency change of the radio; as soon as the animal starts to awaken from hibernation, the radio detunes. During the times when series A readings were obtained, the radio-capsule did not detune. It is our impression that the body temperature of the animal in a variable air temperature is actually maintained by different heart rates. As the burrow temperature becomes colder, due to large changes in air temperature, the heart compensates, perhaps to provide more heat to maintain a constant body temperature.

It should be noted that mammalian hiberation is different in the outdoor environment with variable air temperatures, compared to the constant environment of the cold room. Note that the heart rate outdoors in the steady state of hibernation varied from six to 32 beats per minute (Fig. 4). An examination of the hibernating state in the cold box (Fig. 2) shows that this variation in heart rate did not occur.

The edible dormouse: Dormice occur abundantly in some portions of Europe. Four species were studied by Holisova in the southern Slovakian limestone region. In three months in a small area he trapped 64 specimens of which 30 were the edible dormouse. In our experiments, four specimens were studied by means of temperature radio-capsules and continuous radiometer recording. The skin temperature in the warm environment varied with a day-night rhythm the month of September (25.2-30.2°C between scapulae). A daily photo period of 8 hours was present, which may have acted as a clue to seasonal adjustment. Nevertheless, these dormice when placed in the same cages with the same food in the cold room in darkness did not hibernate for at least 10 days. Within four weeks all specimens hibernated. It would appear that this species requires the conditioning of a cold environment before hibernation is induced.

The garden dormouse: This smaller species (100-170mm) is easily distinguished from the larger (130-190mm) by a sharp smout and black face mask. During the month of September these specimens were maintained in the same fashions as the edible dormouse: unlike Glis, there was no measurable day-night variation in skin temperature (29.7-31.6°C between scapulae). It is this species, however, which when placed in the cold room went into deep dormancy within 48 hours (one specimen required 7 days). Skin temperature varied between 1-2°C above the ambient conditions during hibernation. Details of the initial type of hibernation, compared to that later in the winter, were not determined because the experiment had to be terminated.

Discussion

These results indicate that cold-acclimatization is not necessarily required in preparation for the dormancy of mammalian hibernation. The woodchuck, the hedgehog, and the garden dormouse were all capable of hibernating within one to two days upon exposure in the cold room. Such information has also been obtained on other species, but when these other species were moved from a warm environment into cold, it was not known whether they had already taken on a semi-hibernating condition in the room. In the case of the present report, it is known that a woodchuck, hedgehog, and four Eliomys had maintained normothermic conditions up to the moment of being placed in the cold room.

The other species which had been known to be capable of quickly entering the condition of hibernation are the 13-lined ground squirrel (Folk 1966, Dawe 1970) and the Arctic ground squirrel (Folk 1967). A comparison with the California ground squirrel is of interest (Strumwasser 1959). His animals had been cold-exposed before going into hibernation. When they did begin to enter this state, it took at least six days to attain the condition. Perhaps there is a small amount of this test drop preparation in the case of the woodchuck (Fig. 3), but at least he was in deep hibernation within three days and had not any preparatory cold exposure.

The relationship between sleep and entering hibernation is of interest. In the woodchuck (Fig. 3) the time of early bouts of hibernation coincide with the usual time of day of sleep. This relationship deserves further analysis in hope that knowledge of the condition of sleep will assist us in understanding the nature of the hibernation mechanism (South 1969). The results of the present paper also assist us in understanding the mechanism of hibernation. Although cold air is necessary for actually lowering the body temperature of the animal, apparently previous appreciable exposure to cold air is not necessary to prepare the hypothalamus, the thyroid, the adrenal glands and the heart so that they may permit deep dormancy.

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