ABSTRACT

We investigated the daily rhythm of the response to noradrenaline injections in Djungarian hamsters (Phodopus sungorus sungorus) at neutral ambient temperature, under long photoperiod (L:D 12:12) and after four weeks of acclimation to cold (10°C) and short photoperiod (L:D 8:16). Animals were injected with noradrenaline (0.6 mg/kg) every four hours. Body temperature and gross motor activity were measured with MiniMitter transmitters implanted into abdominal cavity. Additionally, we measured body weight and food intake prior to, and after acclimation. After four weeks of acclimation, the experiment was performed under LD cycle and then repeated during one-day of constant light (LL) and constant darkness (DD). In animals acclimated to L:D 12:12 and ambient temperature of 25°C, noradrenaline injections caused short-lasting increase in body temperature followed by marked decrease. There was no significant difference in the magnitude of the reaction between light and dark phase of the day. After acclimation to cold and L:D 8:16, under LD conditions, we recorded significant differences between the responses to the noradrenaline injections during light and dark phase of the day. Post-injection increase was higher during the day than during the night while following noradrenaline-induced hypothermia was much more pronounced in darkness. In experiments performed after acclimation to cold and short photoperiod but during one day of LL and DD regimes, these differences were attenuated. Data presented here indicate that in cold acclimated hamsters, the response to exogenous noradrenaline depends on the time of injection and it exhibits clear daily rhythm. The rhythmicity is altered under LL and DD regimes. It seems that post-injection increase in body temperature elicits following hypothermia. This hypothermia might be of a great ecological importance. Reasonable lowering of body temperature would be a protective mechanism, allowing for energy charge restoration.

KEYWORDS: Djungarian hamster, circadian rhythm, noradrenaline, hypothermia, body temperature.

INTRODUCTION

When small mammals are exposed to cold, they must produce sufficient heat to compensate for the heat loss, to maintain their body temperature at a constant...
level. When behavioural thermoregulation is not efficient enough, then shivering and/or facultative nonshivering thermogenesis must be involved. Shivering demands a lot of energy and it accelerating air movement and convective heat loss thus further reducing effectiveness of such thermogenesis. Nonshivering thermogenesis (NST) requires the presence of brown adipose tissue (BAT). Undoubtedly, noradrenaline (NA) stimulates metabolism of brown fat and concomitant heat production, a process known as NST, which results in the increase in body temperature. Cold exposure induces increase in thermogenic effectiveness of BAT (Böckler et al., 1982; Haim et al., 1995; Haim et al. 1993; Hirata & Nagasaka, 1981; Rafael & Vsiansky, 1983; Wiesinger et al., 1989a; Wiesinger et al., 1989b) while effect of light can be different. It has been reported several times that acclimation to short photoperiod (SP) enhances nonshivering thermogenesis capacity and increases cold tolerance in Djungarian hamsters (Heldmaier et al., 1981; Heldmaier et al., 1989; Mercer et al., 1994; Wiesinger et al., 1989a), while in Syrian hamsters, NST capacity, measured as noradrenaline turnover, is not increased by short photoperiod alone, without cold exposure (McElroy & Wade, 1986; Viswanathan et al., 1986). Moreover, it might be suggested that light has not only circannual, but also circadian effect.

Under laboratory conditions, injection of noradrenaline usually induces hyperthermia (Haim & Izhaki, 1993; Hayward, 1968; Heldmaier et al., 1981), due to NST activation. The magnitude of this hyperthermia depends on the dose of NA, ambient temperature, the route of administration and animal species. On the other hand, it has been also reported that administration of noradrenaline and other sympathomimetics can exert paradoxical effect on body temperature, i.e., hypothermia. This phenomenon was referred to different adrenoceptors subtypes involvement (Carlisle and Stock, 1991; Carlisle and Stock, 1996; Zylan and Carlisle, 1991; Zylan and Carlisle, 1992).

Nocturnal animals, as well as diurnal ones, exhibit clear circadian rhythm of body temperature with higher values at that part of the day that is correlated with higher activity of animals. Nevertheless, a rise in temperature does not result only from higher activity level (Aschoff, 1983) and involvement of circadian changes in BAT thermogenesis can not be excluded. Body temperature as well as NST capacity are influenced by both circadian and circannual rhythms. In short days, body temperature is kept at a lower level with higher amplitude of ultradian variations than in long photoperiod but circadian rhythm is maintained (Heldmaier et al., 1989). Since body temperature shows circadian rhythm, it is likely that thermogenic response to exogenous noradrenaline may vary within the day. Such a correlation has been found in wood mice, a small rodent that is active throughout the year, in which intensity of the response to noradrenaline injection depended on the time of administration (Haim et al., 1995). It is worthwhile to compare results obtained from animal active throughout the year, with species
exhibiting daily torpor and hibernation. Current experiments were undertaken to verify this hypothesis in Djungarian hamster. It is nocturnal, highly photosensitive animal, depending on changes in photoperiod to cue seasonal acclimation in thermoregulation and reproduction. During fall/winter time, when daylength is shortening, hamsters can reduce their energy requirements by entering into torpor. It is a state of dormancy that enables them to cope with disadvantageous environmental conditions (low ambient temperature, food limitation). Most papers concern seasonal differences in thermogenic capacity of different rodent species (Feist & Morrison, 1981; Gettinger & Ralph, 1985; Heldmaier et al., 1985). To our best knowledge there is no data on daily rhythm of the response to noradrenaline in Djungarian hamsters. Moreover, to evaluate the possibility of the acute effect of light on the response to noradrenaline injections, we performed also two series of experiments under constant light and constant darkness conditions.

MATERIAL AND METHODS

12 adult (3-4 mo old) male Djungarian hamsters (Phodopus sungorus sungorus) weighing 30.79 ± 1.34g were used. Hamsters were housed individually in standard laboratory cages (30×18×17 cm) in which food and water were available ad libitum. Prior to cold acclimation, animals were maintained on 12:12 h light: dark schedule with lights on at 09:00, at an ambient temperature of 25°C. Four weeks later, body weight and food intake were measured, and hamsters were implanted, under Nembutal anaesthesia, with temperature transmitters (MiniMitter, model XM-FH: weight 1.05g, temperature range 10-45°C) into abdominal cavity. After the surgery animals were allowed to recover for one week and then the response to exogenous noradrenaline was examined under short photoperiod regime (L:D 8:16, lights on at 09:00) and at neutral ambient temperature (22 ± 2°C). Every four hours, starting from the beginning of the light phase (09:00 a.m.), noradrenaline ((+)-Arterenol, Sigma) at a dose of 0.6mg/kg was injected subcutaneously (s.c.). It has been shown that this dose induces maximal stimulation of NST (Böckler et al., 1982). Nighttime injections were made under dim red light. Control animals were injected with physiological saline solution, in the same volume under the same regime and schedule. Body temperature and activity were recorded at 1-min intervals. After this experiment, animals were transferred to climatic chamber (T_a 10°C; RH 50 ± 5%; L:D 8:16, lights on at 09:00 a.m.). After four weeks of acclimation to cold (10°C) and short photoperiod (L:D 8:16), body weight and food intake were measured again, and the response to exogenous noradrenaline was reexamined. The experiments were repeated under LL (24 h of lights) and DD (24 h of darkness) conditions, using the same animals. Body
temperatures of animals injected with noradrenaline or saline, expressed as mean values of 30 minutes periods were compared. Data are presented as mean ± SE. For statistical analysis one-way ANOVA was used.

RESULTS

Four weeks of acclimation to cold and short photoperiod did not influence body weight; the mean body weight was 30.79 ± 1.34g before acclimation and after that 28.97 ± 1.00g. However, we managed to record significant increase in food intake due to acclimation. During the four weeks under L:D 12:12 cycle and 25°C hamsters consumed 69.75 ± 2.98g of food per animal and within four weeks of acclimation to short photoperiod and cold this amount increased to the level of 122.48 ± 5.29g (P ≤ 0.001). Per gram of body weight animals used 2.43 ± 0.11 and 4.02 ± 0.135g (P ≤ 0.001) of food, respectively. It indicates that energetic cost of life in cold environment is extremely high.

Noradrenaline given under L:D 8:16 and neutral ambient temperature (22 ± 2°C) caused short (up to 30 min) increase in body temperature followed by significant decrease (Fig. 1). The maximal increase (+1.04°C) was recorded after the injection at 13:00 and it lasted 30 min (Table 1, Fig. 1). One hour later (14:30-15:00) deep hypothermia developed, and noradrenaline-treated animals had lower body temperature by 1.44°C than saline-injected ones (P ≤ 0.001, Table 2). The same pattern of the response to noradrenaline was observed after each injection, except the time 21:00 and 05:00 when increase in body temperature was delayed and it was shorter. Then, significant hypothermia developed again (Fig. 1). Nevertheless, within 30 minutes after the injections, increase in body temperature was
TABLE 1. Increase in body temperature caused by injections of saline and noradrenaline, counted as the difference between mean body temperature within the period of 30 minutes after the injections and 30 minutes before. Time of darkness is indicated by shaded area.

<table>
<thead>
<tr>
<th>Time of injection</th>
<th>Neutral ambient temperature</th>
<th>After 4 weeks of acclimation to 10°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L:D 8:16</td>
<td>LL</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td>NA</td>
</tr>
<tr>
<td>09:00</td>
<td>+0.29</td>
<td>+0.72</td>
</tr>
<tr>
<td>13:00</td>
<td>+0.37</td>
<td>+1.04</td>
</tr>
<tr>
<td>17:00</td>
<td>+0.39</td>
<td>+0.70</td>
</tr>
<tr>
<td>21:00</td>
<td>+0.52</td>
<td>+0.34</td>
</tr>
<tr>
<td>01:00</td>
<td>0</td>
<td>+0.52</td>
</tr>
<tr>
<td>05:00</td>
<td>+0.36</td>
<td>+0.37</td>
</tr>
</tbody>
</table>

TABLE 2. Magnitude of hypothermia (in °C) in NA-injected hamsters (expressed as the difference between noradrenaline- and saline-injected animals) in neutral ambient temperature and after acclimation to cold and short photoperiod (experiments under LD, LL, DD regimes). Time of darkness is indicated by shaded area. All values are significantly different at the level of $P \leq 0.001$, except #: $P \leq 0.05$. Avg-average degree of hypothermia within four hours after each injection, Max- the maximal hypothermia and time of its appearance within periods of four hours.

<table>
<thead>
<tr>
<th>TIME</th>
<th>22°C</th>
<th>10°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>Max</td>
</tr>
<tr>
<td>09:00-13.00</td>
<td>–0.72</td>
<td>–0.27</td>
</tr>
<tr>
<td>(10:30-11:00)</td>
<td>–1.44</td>
<td>ns</td>
</tr>
<tr>
<td>13.00-17.00</td>
<td>–0.69</td>
<td>ns</td>
</tr>
<tr>
<td>(14:30-15:00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.00-21.00</td>
<td>–0.34</td>
<td>–0.10</td>
</tr>
<tr>
<td>(18:00-18:30)</td>
<td>–0.83</td>
<td>–0.97</td>
</tr>
<tr>
<td>21.00-01.00</td>
<td>–0.48</td>
<td>–0.37</td>
</tr>
<tr>
<td>(22:00-22:30)</td>
<td>–1.23</td>
<td>–0.81</td>
</tr>
<tr>
<td>01.00-05.00</td>
<td>–0.70</td>
<td>–0.34</td>
</tr>
<tr>
<td>(03:00-03:30)</td>
<td>–0.67</td>
<td>–0.58</td>
</tr>
<tr>
<td>05.00-09.00</td>
<td>–0.36</td>
<td>–0.30</td>
</tr>
<tr>
<td>(05:00-05:30)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
higher in NA-treated animals than in control ones, except the injections at 21:00 and 05:00 (Table 1). There was no difference between light and dark phase of the day. The most pronounced decrease in body temperature, exceeding 1°C, was recorded after the injections at 13:00 and 01:00 (Table 2).

Noradrenaline given under L:D 8:16 cycle and ambient temperature of 10°C caused decrease, and not increase in body temperature but daily rhythmicity was clear. This hypothermic response was much more pronounced during night than during daytime. The duration of hypothermia depended on the time of injection and varied from 90 min to 4 hours, i.e., it was shorter within the light phase of the day (Fig. 2). When 4-hour periods between injections were taken for comparison, then the deepest hypothermia was observed after injection at 21:00 (mean decrease in body temperature was 0.37°C). On the other hand, irrespective of the light/dark phase, the drop in body temperature in NA-treated animals was the deepest 30-90 min after injections, e.g., the difference between body temperature of control and noradrenaline injected animals was 0.97°C and 0.81°C at 21:30-22:00 and 01:30-02:00, respectively (Table 2). There is however, some increase in body temperature after NA injections but it is similar or smaller than after saline administration (Table 1) so it could not be regarded as the calorigenic response to noradrenaline. Nevertheless, that increase is higher during the day that during the night.

In constant light (LL), noradrenaline-induced hypothermia was more pronounced and after the injection at 17:00 the difference between body temperature of controls and NA-injected animals averaged 0.60°C (Table 2). The differences in magnitude of hypothermia between day and night time were less pronounced than under the LD cycle. Moreover, the 30 min period of the deepest hypothermia was delayed in comparison with the response under the LD regime. Noradrenaline
injections in constant darkness did not induce marked drop in body temperature. Maximal difference was observed after the injection at 21:00 (21:00-01:00), and on average it did not exceed 0.15°C. Nevertheless, within a period of 21:30-22:00, temperature of noradrenaline-injected animals was 0.88°C lower. After the injection at 05:00, body temperature was even higher in noradrenaline-injected animals (+0.17°C, \( P \geq 0.001 \)) than in control ones (Table 2).

In the experiment performed in neutral ambient temperature as well as after 4-weeks acclimation to cold and short photoperiod, in control group of hamsters as well as in noradrenaline-injected animals, body temperature was higher during night than during daytime (Table 3). In animals maintained on an 8:16 h light:dark schedule and acclimated to cold, the magnitude of NA-induced hypothermia during the day was clearly less pronounced than during the night (–0.05 and –0.28°C, respectively). In constant light and constant darkness this difference was attenuated. Under LL regime, within 24 h, the degree of hypothermia was similar to that one observed during darkness in LD conditions. In constant darkness, slight hypothermic influence of noradrenaline was recorded only within corresponding light phase of the day (Table 3).

Since Djungarian hamster is typical nocturnal species, it shows higher activity at night, with the maximum around 20:00-21:00. During one day of constant light
the evening peak occurs in saline-injected animals only, but even in this group activity is diminished during the latter part of darkness. In hamsters injected with noradrenaline, activity was continuously kept at low level without that characteristic evening peak. Under one-day DD conditions, activity level of control animals has not been elevated during the scheduled light time (09:00-17:00) and it has been slightly higher after 17:00 (Fig. 3 A, B).

**DISCUSSION**

After four weeks of acclimation to cold and short photoperiod we recorded slight decrease in body weight of Djungarian hamsters. According to the literature (Hoffmann, 1973; Mercer et al., 1994; Wiesinger et al., 1989a) as well as our other experiments (unpublished data), significant decrease can be observed following longer period of acclimation (16 weeks). Nevertheless, food intake was almost 2-
fold higher in cold than in neutral temperature. That was a result of higher energy demand in cold environment and it clearly shows that energetic cost of life in cold is extremely high. After four weeks of acclimation animals are not able to reduce their energy requirements by entering torpor. These results are in agreement with previous reports concerning the change of Djungarian hamsters into the ‘winter status’, when marked decrease in body weight, food intake and molt to a white pelt can be easily seen (Hoffmann, 1973; Mercer et al., 1994).

Undoubtedly, brown adipose tissue is the main site for nonshivering thermogenesis. Noradrenaline binds to β3-adrenoceptors on the membrane of adipocytes (Cannon et al., 1996) and induces a sequence of reactions, increasing heat production via the mechanism of NST. Under laboratory conditions, injection or infusion of NA induces increase in metabolic rate, measured as increase in oxygen consumption or in body temperature (Haim & Izhaki, 1993; Hayward, 1968; Heldmaier et al., 1981).

Since the efficiency of brown fat in Djungarian hamster is high and moreover the thermogenic properties of this tissue are enhanced with acclimation to cold and short photoperiod (Böckler et al., 1982; Heldmaier et al., 1981; Wiesinger et al., 1989a; Wiesinger et al., 1989b), we did not expect hypothermic influence of noradrenaline.

In present experiments, noradrenaline given under L:D 8:16 and neutral ambient temperature (22 ± 2°C) caused short (up to 30 min) increase in body temperature followed by marked decrease. That increase was significantly higher in NA-treated animals than in saline-injected ones, thus reflecting calorigenic action of noradrenaline. The same pattern of the response to exogenous noradrenaline, i.e., short-lasting increase followed by evident decrease was recorded after each injection. There was no difference between light and dark phase of the day but the magnitude of the increase was higher during the light phase when body temperature was kept at the lower level.

Djungarian hamsters acclimated to cold (10°C) and short photoperiod (L:D 8:16) showed clear daily rhythm in the response to injections of noradrenaline. Under LD regime, the intensity of hypothermia in noradrenaline-injected animals was much higher during darkness than during light phase of the day. The hypothermia was preceded by short increase in body temperature, like in nonacclimated animals, but that increase was markedly attenuated. In comparison with nonacclimated hamsters it was smaller during the day and almost completely diminished at night.

During one day of LL and DD conditions, the increase in body temperature after saline injections was similar to that observed under LD regime but response to noradrenaline was different. Under LL conditions marked increase was observed almost after each injection (except the first and the last ones, i.e., at 09:00 and 05:00), and then significant hypothermia occurred, independently of
the ‘day/night’ time. In constant darkness, slight increase was recorded only after injections at 09:00 and 13:00 and hypothermia was reduced. It seems that increase in body temperature elicits following hypothermia.

It has been shown that in cold-acclimated rats administration of noradrenaline markedly increased blood flow to brown adipose tissue and heart while significant decrease occurred to the muscles and visceral tissues (Foster & Frydman, 1978; Ma & Foster, 1984). Additionally, the increase in BAT blood flow was associated with decline in tissue ATP. Since brown fat plays very important role in heat production in cold-acclimated animals and maintaining euthermy, hypothermia might serve as important protective mechanism. When animals keep body temperature at the lower level, they do not use brown fat maximally thus allowing for tissue energy charge restoration.

Cold-acclimated hamsters exhibited more pronounced hypothermia at night and higher post-injection increase in body temperature during the day. In nonacclimated animals, there was no difference in day/night response to NA injections. Thus, it could be suggested that acclimation to low ambient temperature is more potent factor altering response to noradrenaline than light. The finding of day/night differences in the magnitude of increase in body temperature after noradrenaline injections corresponds with suggestion by Watts and Refinetti (1996) that sensitivity of autonomic thermoregulatory system to cold undergo circadian variations. They found that cold-induced thermogenesis in golden hamster was greater during the day that during the night, i.e., when body temperature was kept at the lower level. Opposite finding was reported by Haim et al. (1995) who recorded the minimal response to noradrenaline in wood mice (*Apodemus sylvaticus*) in the late afternoon, i.e., when body temperature was kept at the lowest level. Rectal temperature after noradrenaline injections was measured at three different times of the day in mice acclimated to short or long photoperiod (8 or 16 hours of lights, respectively) and near-neutral ambient temperature (24°C). The response to noradrenaline was greater in animals acclimated to short days but, irrespective of the acclimation regime, the increase in temperature was the greatest at night and the smallest in the late afternoon. Haim et al. (1995) concluded that response to noradrenaline followed a daily rhythm of body temperature and suggested that this reaction could be a result of lower GDP binding since Redlin et al. have found positive correlation between body temperature and GDP binding to the brown fat mitochondria in juvenile rats (Redlin et al., 1992). Therefore, it is likely that effectiveness of exogenous noradrenaline is lower when body temperature is low. Data presented here contradict such hypothesis since the increase in body temperature in nonacclimated as well as cold-acclimated hamsters was higher during the light phase of the day when body temperature was kept at the lower level.

Sensitivity of β-adrenoceptors to noradrenaline may also vary within the day, thus further contributing to observed rhythmicity. Different sensitivity of the
receptors might be a cause of different degree of noradrenaline-induced hypothermia. On the other hand, endogenous noradrenaline may interact with exogenous one, since the negative feedback resulting in the decreased production and release of endogenous stores of noradrenaline has been described (Starke, 1989). We reported the deepest hypothermia about one hour after the injections, irrespective of the time of injection. Therefore it could result from an inhibition of thermogenesis due to a decreased level of endogenous noradrenaline. Zylan and Carlisle reported that in nonacclimated ($T_A 25^\circ C$) and cold-acclimated ($T_A 5^\circ C$) rats noradrenaline decreased oxygen consumption and body temperature during experiments performed below acclimation temperature. In nonacclimated animals core temperature fell by about $2.2^\circ C$ while in cold-acclimated ones by about $1.3^\circ C$ (Zylan & Carlisle, 1992). They suggested that hypometabolic effect of NA could be mediated mainly by presynaptic $\alpha_2$-adrenoceptors. In present experiments, control group of Djungarian hamsters was housed at $25^\circ C$ and noradrenaline was given at $22^\circ C$. $22^\circ C$ is neutral temperature for these animals but it can not be excluded that such lowering of temperature from 25 to $22^\circ C$ did not alter obtained results. On the other hand, cold-acclimated hamsters were treated with noradrenaline at the acclimation temperature and the decrease in body temperature persisted. Nevertheless, the magnitude of hypothermia as well as short, post-injection increase in body temperature was higher in control, nonacclimated hamsters. It can be presumed that control animals could not dissipate heat in thermoneutral environment as effectively as cold-acclimated ones, resulting in the higher increase in body temperature.

Endogenous noradrenaline exhibits circadian rhythmicity thus daily differences in the degree of hypothermia might directly result from the interaction between endo- and exogenous noradrenaline. Miguez et al. (1996) reported nocturnal increase in noradrenaline content in the pineal gland of female Djungarian hamsters acclimated to short photoperiod (10 hours of light) but not in animals acclimated to long days (16 hours of light). Moreover, acclimation to short photoperiod induced increase in NA turnover in brown adipose tissue (McElroy et al., 1986). Since our animals were acclimated to short days, we can speculate that the strongest reaction observed at night might be connected with higher noradrenaline turnover. Nevertheless, the mechanism underlying such a correlation remains unknown.

The highest degree of hypothermia after noradrenaline injections in constant light (LL) could be also partially explained by lower motor activity of the animals. Noradrenaline-treated hamsters showed similar patterns of activity under LD and DD regimes but it was altered under LL conditions; there was no peak of activity that was observed under LD and DD conditions during the initial half of night. At that time, the difference between temperature of control and noradrenaline-injected animals was most pronounced and hypothermia after the injection at
17:00 was maintained till 22:30. The animals were adapted to change from day to night at 17:00, hence the lack of light could be the most apparent signal for them. Body temperature rhythm does not result from the rest/activity cycle (Aschoff, 1983) but under LL regime the amplitude of endogenous rhythm is suppressed (Witting et al., 1995). However, in present experiments, only acute influence of light on the autonomic thermoregulatory system would be rather involved.

In nonacclimated hamsters, the magnitude of noradrenaline-induced hypothermia was similar throughout the day while in cold-acclimated animals it was much more pronounced at night than during the day. Nevertheless, body temperature recorded after NA injections at night has never fallen down below the daytime level. It suggests that Djungarian hamsters do not allow body temperature to drop below dangerous level and actively prevent life-threatening hypothermia. The finding of noradrenaline-induced hypothermia might be of great ecological importance. In natural environment, such precise thermoregulation would be very beneficial. Djungarian hamsters are nocturnal animals so they are usually exposed to low ambient temperatures during darkness. After exposure to cold (e.g., during the time spent outside the nest) that is connected with intensive nonshivering thermogenesis, they could maintain body temperature at the lowest level, what would allow for energy restoration.

From the results of our present experiments it is evident that in cold-acclimat-ed hamsters thermal response to exogenous noradrenaline is strongly affected by the time of injection, i.e. hypothermia is much higher during darkness than during light phase while post-injection increase in body temperature exhibits opposite dependence. The magnitude of hypothermia seems to be correlated with the degree of post-injection increase in body temperature.

It is the first report describing a daily rhythm of the response to noradrenaline in Djungarian hamsters. Since the rhythmicity of the response to noradrenaline was found in wood mice, other nocturnal but not torpid rodent, it would be very interesting to evaluate this rhythm, if it exists, in any hibernating species as well as in animals with opposite pattern of activity (diurnal ones). Moreover, although in noradrenaline-treated hamsters significant hypothermia developed, the animals did not permit a dangerous drop in body temperature at night. Such reasonable lowering of body temperature might enhance their chance of survival in cold environment since hypothermia could serve as very important period allowing for energy restoration.

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