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Body Temperature Daily Rhythms in the Striped Mouse *Rhabdomys pumilio*: The Effects of α and β Blockade

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HAIM, A., R. J. VAN AARDE AND N. ZISAPEL. *Body temperature daily rhythms in the striped mouse Rhabdomys pumilio: The effects of α and β blockade.* PHYSIOL BEHAV 63(5) 889–893, 1998.—Body temperature (T_b) daily rhythms and the effects of α and β blockade were studied in the South African diurnal striped mouse *Rhabdomys pumilio*. Eleven mice (8 males and 3 females) with a body mass of 42.7 ± 7.8 g (mean ± SD) were tested. Mice were acclimated to a 13 h:11 h light–dark photoperiod at an ambient temperature of 25°C. To assess the daily rhythm of pineal melatonin secretion, urinary 6-sulfatoxymelatonin (6-SMT) was determined. Mice displayed a robust T_b daily rhythm with an acrophase in the dark period, which is unexpected for a diurnal species. The nocturnal increase in T_b was accompanied by a significant rise in urinary 6-SMT. The β blocker propranolol (4.5 mg/kg), injected 1 h before lights-off, resulted in a higher T_b value, whereas the α blocker prazosin (1 mg/kg) blocked the increase of T_b during the dark period. Prazosin also significantly attenuated the nocturnal increase of urinary 6-SMT. These results are in agreement with those obtained from the golden spiny mouse *Acomys russatus* and support the idea that small diurnal mammals retain the T_b rhythm of a nocturnal rodent. They also suggest that pineal melatonin secretion in these rodents is regulated by α rather than by β receptors. © 1998 Elsevier Science Inc.

Diurnal rodent | Hyperthermia | Body temperature daily rhythms | Arid environment | Pineal | Melatonin
β-Adrenergic | β and α receptors | Activity

MAMMALS originated as nocturnal animals. Nocturnal activity is advantageous for small (body mass < 100 g) desert-adapted mammals because they avoid overheating and conserve water (24). However, there are several known exceptions, such as the golden spiny mouse *Acomys russatus* from the Rift Valley in Israel (25) and the striped mouse *Rhabdomys pumilio* from South Africa (26). Recent studies on the body temperature (T_b) rhythms of *A. russatus* revealed that, although this species is diurnal, the highest T_b values are recorded in the dark phase of their daily cycle (3,14,16,17,23). It was also noted that the β blocker propranolol (4.5 mg/kg) did not block pineal melatonin synthesis or attenuate the nocturnal rise in T_b, results which differ from those obtained for nocturnal rodents such as the rat and the hamster (16). However, the α blocker prazosin (1 mg/kg) caused a decrease in T_b (13). From the results of these studies it was concluded that, unlike the rat, production and secretion of pineal melatonin in *A. russatus* are stimulated by α- and suppressed by β-adrenergic receptors.

The striped mouse *R. pumilio* is a diurnal rodent that is widely distributed, ranging from hot and arid ecosystems, such as the Namib desert, to colder and more humid ones, such as the Dragensberg Mountains at altitudes of 2700 m. Various thermoregulatory aspects of this species have been studied (4,8–10). It has been noted that this species responds to a longer scotophase by a significant increase in resistance to low ambient temperatures (7,11). Melatonin treatment was found to increase heat production, body temperature, and enzymatic activity of malate dehydrogenase (MDH) and lactate dehydrogenase (LDH) (12). Daily activity patterns were also studied in this species under laboratory conditions (19). The activity of this species peaked at dusk and dawn; therefore, it was concluded that *R. pumilio* is crepuscular and it was assumed that this pattern of activity was associated with *Hodotermes* predation. Because *R. pumilio* is a small rodent, yet active in the daytime, even in hot and dry environments such as the Kalahari and Namib deserts, it seemed of great interest to study the T_b daily rhythms of this species and to compare them with those of *A. russatus* as well as to analyze the different effects of α and β blockage. Furthermore, we wanted to assess the daily rhythm of pineal melatonin secretion by urinary 6-sulfatoxymelatonin (6-SMT) and the effect of α blockade.

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TABLE 1

MESOR, AMPLITUDE, AND ACROPHASE OF BODY TEMPERATURE DAILY RHYTHMS IN THE STRIPED MOUSE *RHABDOMYS PUMILIO*

	Control	β Blocker	
Mesor (°C)	38.2 ± 0.26	38.4 ± 0.24	$p < 0.001$
Amplitude (°C)	0.15 ± 0.18	0.11 ± 0.17	NS
Acrophase (h)	19.3 ± 6.3	24.0 ± 0.77	$p < 0.05$
	Control	β Blocker	
Mesor (°C)	38.6 ± 0.29	38.5 ± 0.41	NS
Amplitude (°C)	0.34 ± 0.41	0.06 ± 0.08	NS
Acrophase (h)	20.8 ± 7.9	17.7 ± 7.7	NS

Values are mean ± SD; $n = 11$ for mice injected with the β blocker propranolol (4.5 mg/kg of body mass, i.p.) 1 h before lightsoff, and $n = 9$ for mice injected with the α blocker (1 mg/kg of body mass, i.p.).

MATERIALS AND METHODS

Eleven *R. pumilio* (eight males and three females) with a body mass of 42.7 ± 7.8 g (mean ± SD) were trapped on the Proof-Place outside Pretoria, South Africa. Mice were acclimated to a 13 h:11 h light–dark photoperiod regime at a constant ambient temperature of 25°C for 3 weeks prior to study. Lights were on between 0600 and 1900 hours and a dim red light was kept on constantly. Mice were housed individually in a cage and rat pellets and water from a bottle were offered ad lib.

T_b *Daily Rhythms*

For measuring T_b ($n = 11$) a copper–constantan thermocouple connected to an APPA 51 digital thermometer (Appa Technology Corp., Taipei, Taiwan) was used. T_b was measured over 32 h in intervals of 4 h starting at 1000 hours. Then the β blocker propranolol (Sigma, 4.5 mg/kg of body mass) was injected intraperitoneally (i.p.) 1 h before lights-off and T_b was measured over the next 24 h. One week after propranolol injection, the daily T_b rhythm ($n = 9$) was measured again over 28 h. Then the α blocker prazosin (Sigma, 1 mg/kg of body mass) was injected intraperitoneally 1 h before lights-off and T_b was recorded for 24 h. Prior to the propranolol injection, 0.2 mL of saline was injected ($n = 6$) and T_b was recorded for 24 h in intervals of 4 h.

Urinary 6-SMT Analysis

Urine samples for analyzing 6-SMT were collected over 24 h for control and during the dark period after injection of the α blocker. Urinary 6-SMT was measured in duplicate by radioimmunoassay (Stockgrand Ltd., Surrey, UK) as described by Arendt (1). The 6-SMT excretion rates were calculated per hour from the total amount in each sample divided by the 6-h collection time interval. Because melatonin is only excreted during darkness (22), only the sample collected between 2400 and 0600 hours was analyzed for mice treated with prazosin.

Statistics

All values for T_b and 6-SMT are given as means ± SD. Statistical analysis of the data was performed by one-way ANOVA followed by Scheffe's multiple comparison test. To assess the effect of prazosin on 6-SMT, a Student's *t*-test was used. T_b rhythm patterns were analyzed by fitting to a cosinor model (18).

RESULTS

The striped mouse *R. pumilio* displayed a robust T_b daily rhythm. Minimal T_bs were recorded during the photophase, whereas maximal values were recorded during the scotophase 3 h after lights-off. Values during the second measurement ($n = 9$) were higher at 2200 hours, and high values were also recorded at 0200 hours. The acrophase (the time of day at which the peak of the measured variable occurs) was recorded in the dark period (Table 1). The saline injection had no effect on T_b values and they were the same as those of the control before propranolol (therefore, they were not plotted on Fig. 1).

The administration of the β blocker propranolol 1 h before lights-off kept T_b at higher values for a period of 8 h and T_b decreased with onset of the light period (Fig. 1). In analyzing the T_b daily rhythms, we noted a significant change in the mesor ($p < 0.001$) and acrophase ($p < 0.05$) of the 36 β-blocker-injected mice

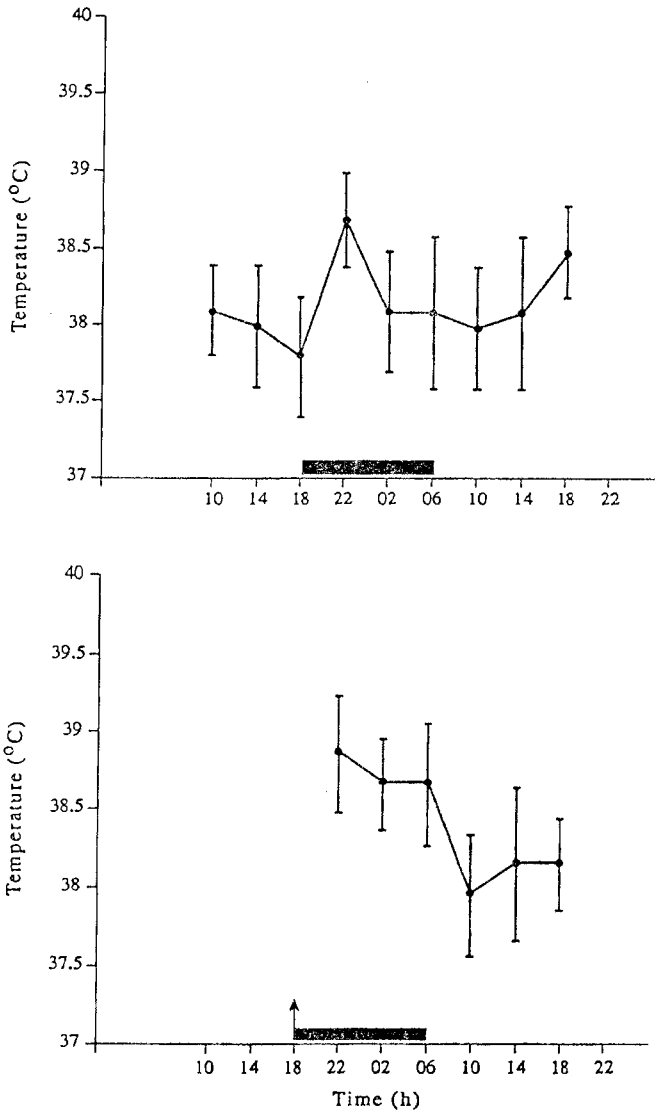

FIG. 1. Response of body temperature daily rhythms in the striped mouse *Rhabdomys pumilio* to the β blocker propranolol (4.5 mg/kg body mass, i.p.) injected 1 h before lights-off. Time of injection is indicated by an arrow. Values are means ± SD of $n = 11$.

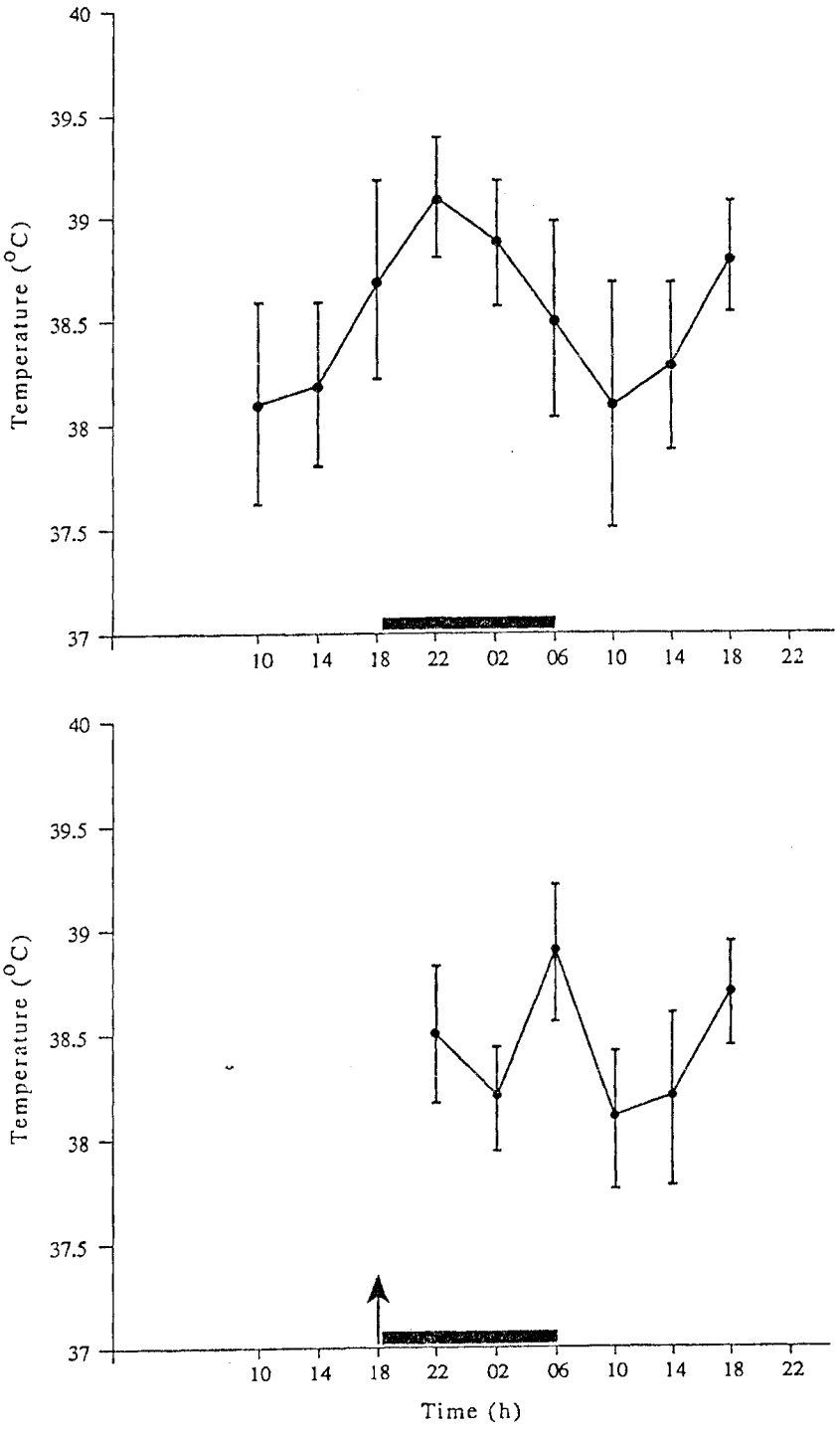

FIG. 2. Response of body temperature daily rhythms in the striped mouse *Rhabdomys pumilio* to the α blocker prazosin (1 mg/kg body mass, i.p.) injected 1 h before lights-off. Time of injection is indicated by an arrow. Values are means ± SD of $n = 9$.

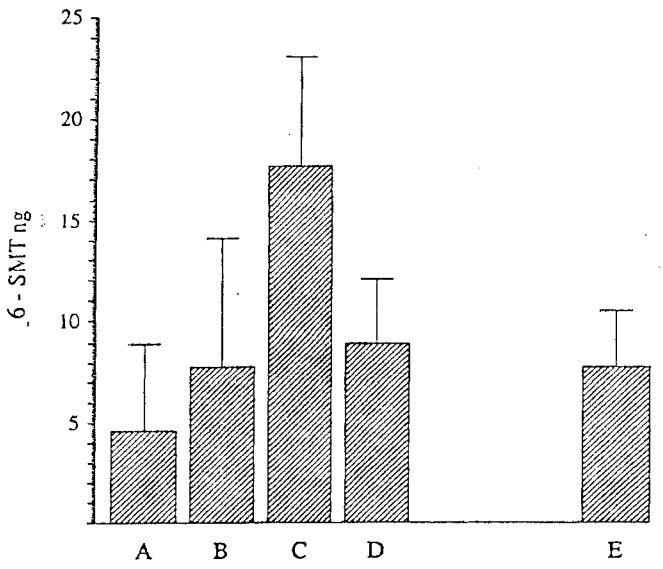

FIG. 3. Daily rhythms of 6-SMT secreted in the urine of the striped mouse *Rhabdomys pumilio*: (A–D) control samples collected at intervals of 6 h starting at 1200 hours; (E) a sample collected between 2400 and 0600 hours after injection of the α blocker prazosin (1 mg/kg of body mass, i.p) 1 h before lights-off. All values are means ± SD of the same individuals (n = 5). C is significantly ($p < 0.05$) higher than A, B, and D; E is significantly ($p < 0.05$) lower than C.

when compared with control mice (Table 1). The administration of the α blocker prazosin attenuated the increase of T_b during the scotophase and T_b increased only at 0600 hours with onset of the photophase (Fig. 2).

Urinary 6-SMT showed a daily rhythm with a significant [$F(3, 16) = 4.55$, $p < 0.05$] increase during the second half of the dark period. The administration of the α blocker prazosin blocked this increase, and significantly ($p < 0.05$) lower 6-SMT values were recorded during the second half of the dark period compared with control values (Fig. 3).

DISCUSSION

The daily rhythm of body temperature is an outcome of two physiological processes, namely, heat production and heat dissipation. In their review on the circadian rhythm of body temperature, Refinetti and Menaker (20) stated that in diurnal animals the acrophase of the T_b rhythm occurs during the daytime, whereas in nocturnal animals it occurs during the nighttime. Although *R. pumilio* is diurnal, or according to Perrin (19), a crepuscular but not a nocturnal species, its acrophase is recorded during the dark phase of the 24-h cycle. Similar results were obtained for *A. russatus*, a diurnal species with a body mass of about 60 g (3,15). Both species seem to be active when their body temperature is in the lower range of the cycle. Because the published data on T_b daily rhythms of diurnal rodents are from larger species (21) and from the recently studied Chilean degus *Octodon degus* (20), it may be assumed that the differences partly emerge from body size.

Behavioral thermoregulatory experiments carried out on thermal gradients using nocturnal species, the rat and the hamster, revealed that during the T_b acrophase, which occurs at the time of activity, low ambient temperatures were selected by both species (5,6). Similarly, the diurnal *O. degus* showed the same phenomenon by selecting lower temperatures during the acrophase (20). The problem of body size in the T_b daily rhythm of diurnal mammals exposed to excessive heat was emphasized by Bartholomew (2). Whereas a large mammal such as the camel with a body mass on the order of 100 kg increases its T_b, the antelope ground squirrel with a body mass on the order of 100 g relies on escape behavior to a cool burrow when faced with excessive heat. However, the body mass of *R. pumilio* is on the order of 10 g and lacks a thermal refuge. The small body size of mice would seem to be unfavorable for adaptation to daily dry and hot conditions (10) and for maintaining high T_b values, because the heat production from motor activity will further increase T_b in the daytime and foraging time will reduced. Thus, because of these ecophysiological constraints, small diurnal rodents like *R. pumilio* and *A. russatus* will retain a T_b daily rhythm of a nocturnal rodent.

The apparent difference in the control values between the two groups of *R. pumilio* may emerge from different sample size, n = 11 for the β blocker and n = 9 for the α blocker.

Many studies have shown that in mammals, regardless of their period of activity, the production and secretion of pineal melatonin occur during the scotophase (22). Pineal melatonin synthesis in the rat, a nocturnal rodent, was found to be regulated by β-adrenergic receptors. A blockage of such receptors by propranolol blocked melatonin secretion (27). In contrast, the increase in nocturnal melatonin secretion of the sheep, a diurnal mammal, was blocked by prazosin but not by propranolol (28). Recently, it was discovered that propranolol administered to the golden spiny mouse *Acomys russatus* increased pineal melatonin secretion and this increase was correlated with an elevation in T_b. Therefore, it was suggested (16) that the production and secretion of pineal melatonin in diurnal mammals are not controlled solely by β-adrenergic signals. However, the results of the present study show that prazosin significantly decreased urinary 6-SMT during the dark period, which presumably indicates a decrease in pineal melatonin production and/or secretion.

In long-day-acclimated (16 h light:8 h dark) *A. russatus*, the blockade of pineal β receptors by propranolol administered 1 h before the scotophase resulted in a significant increase of T_b compared with control T_b values. However, a decrease was noted under the same conditions when the α blocker prazosine was administered (13).

Therefore, the results of the present study together with those obtained from studies on *A. russatus* support the idea that small diurnal rodents retain a T_b daily rhythm of a nocturnal species presumably to avoid hyperthermia during activity. They also suggest that in diurnal rodents pineal melatonin production and/or secretion during the dark phase is controlled by α rather than by β receptors.

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