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The Temperature Selected by Thermoregulatory Behavior is Affected by Initial Ambient Temperature

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Abstract The aim of the present study is to investigate how the initial ambient temperature affects the response of behavioral thermoregulation, and to clarify if there is a shift in temperature selected by thermoregulatory behavior after the animals are moved to the new ambient temperature from the temperature already adapted. It was revealed that the temperature selected by thermoregulatory behavior was affected by the initial ambient temperature at which animals adapted before the exposure to new ambient temperature.

Key Words : Temperature regulation, Behavioral thermoregulation, Operant behavior, Heat-escape behavior, Set point

Introduction

Homeothermic animals are able to regulate their body temperature with a certain degree of accuracy under changing external and internal conditions. It is well established that the regulation of body temperature is accomplished by both autonomic and behavioral thermoregulatory responses[1,2].

As concerns with the studies on behavioral thermoregulation, it was not until the last 30 years that operant behavior was used as a method to determine quantitatively the thermoregulatory behaviors. This technique developed by Weiss and Laties (1961) consists in training bar-pressing operant behavior in order to receive a thermally comfortable reward of warmth or cold[3]. This approach gave valuable new insights into the process of temperature regulation. In the previous studies, the quantitative relationship between deep body (core) and skin temperatures have been extensively examined with a contemporaneous development of thermoregulatory operant behavior. Consequently, it has been proposed that the error signals generated by displacement of central or peripheral temperature are driving forces for behavioral as well as autonomic thermoregulatory responses[4-8].

When animals are exposed to different ambient temperature, it is likely that the behavioral responses depend on the degree of central or peripheral error signals generated by the thermal load. In our daily life, we sometimes notice that thermal comfort or discomfort caused by changes in the ambient temperature is affected by the initial ambient temperature. However, previous studies have not shown whether the thermoregulatory behavior is modulated by the initial ambient temperature before exposure to heat or cold. The purpose of the present study is to investigate how the initial ambient temperature affects the magnitude of the reponses by behavioral thermoregulation, and to clarify if there exist shifts in the temperatures selected by thermoregulatory behavior after the animals are moved to the new ambient temperature from the temperature already adapted.

Methods

Six male albino rats (Wistar strain) weighing 250-300 g were used. An operant box, with a Plexiglas cylinder (23 cm diameter, 35 cm high) mounted at the perforated floor and fitted with a blower fan at the bottom, was utilized in the study of the heat-escape operant behavior. An infrared lamp (100 W or 200 W), centered over the cylinder, was placed at the adjustable height over the floor. The operant box was placed in the temperature-controlled room at 20 ± 1℃ or 27 ± 1℃. The operant box was also fitted with two T-shaped bars protruding into the box. The lamp was normally on and the fan was normally off. On pressing one bar, the lamp was switched off for a period of 8 sec and, simultaneously, the fan was activated, which drew the room air into the box during this 8 sec. The other bar was a dummy to ensure that the bar-pressing motion was selective. In this way the animals could cool themselves and control the temperature in the box.

Animals were trained for heat-escape operant behavior for 90 min every day over 2 to 3 weeks. During the training, an infrared lamp (200 W) was placed 37 cm over the floor and the room temperature was set at 20 ± 1℃. Furthermore, during the training, the rectal temperature was monitored with a copper-constantan thermocouple inserted 6 cm beyond the anus, for the purpose to accustom to the thermocouple probe inserted into the rectum. At the end of the training program, a stable bar-pressing to escape from heat was established. Then all animals, well trained for the operant behavior, were subjected to experiments.

The heat-escape operant hevavior in six animals was investigated under the following experimental conditions : Grade 1, an infrared lamp (100 W) was placed at 37 cm over the floor at 20 ± 1℃ of room temperature ; Grade 2, lamp (100 W) was 37 cm over at 27 ± 1℃ ; Grade 3, lamp (200 W) was 37 cm over at 20 ± 1℃ ; Grade 4, lamp (200 W) was 30 cm over at 20 ± 1℃ ; Grade 5, lamp (200 W) was 37 cm over at 27 ± 1℃ ; Grade 6, lamp (200 W) was 30 cm over at 27 ± 1℃. Fig. 1 shows the chronographical changes in the box temperature (Ta), where no animal was introduced, under the six experimental conditions (Grade 1-6), being kept the infrared lamp on for 60 min under different room temperatures (20 ± 1℃ and 27 ± 1℃). As shown in Fig. 1, the higher the Grade was, the more Ta increased 15 min after the lamp was switched on.

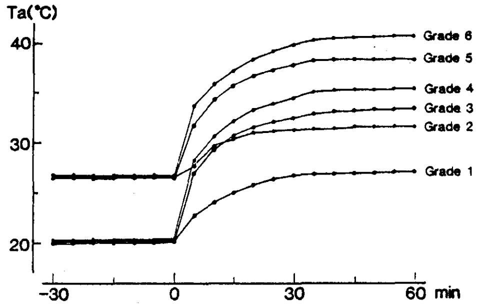

Fig. 1 Chronographical changes in the box temperature (Ta) under the six experimental conditions (Grade 1-6), where no animal was introduced.

On the day of the experiment, animals were placed in the operant box for a period of 120 min to stabilize the body temperature. Throughout the experiment, their rectal (Tre), tail skin (Ts) and the box (Ta) temperatures were measured every 3 min by a copper-constantan thermocouple. The rate of bar-pressing per 3 min was also recorded by a counter and printed out every 3 min. The experiment was initiated when an infrared lamp was switched on under various experimental conditions (Grade 1-6).

Results

Changes in the Ta, Ts, Tre and the bar-pressing rate of six experimental groups (Grade 1-6) are shown in Fig. 2. In Grade 2-6, the Tre and the bar-pressing rate increased with an increase of the grade of thermal load. On the other hand, in Grade 1, animals rarely pressed the bar, even though the Ta increased to about 27℃ and the Ts increased to about 32℃. The date obtained in Grade 1 were excluded from the following analysis.

The relations between the bar-pressing rate and either Tre, Ts or Ta are summarized in Fig. 3, 4, and 5, respectively. In the figures, the mean changes in the bar-pressing

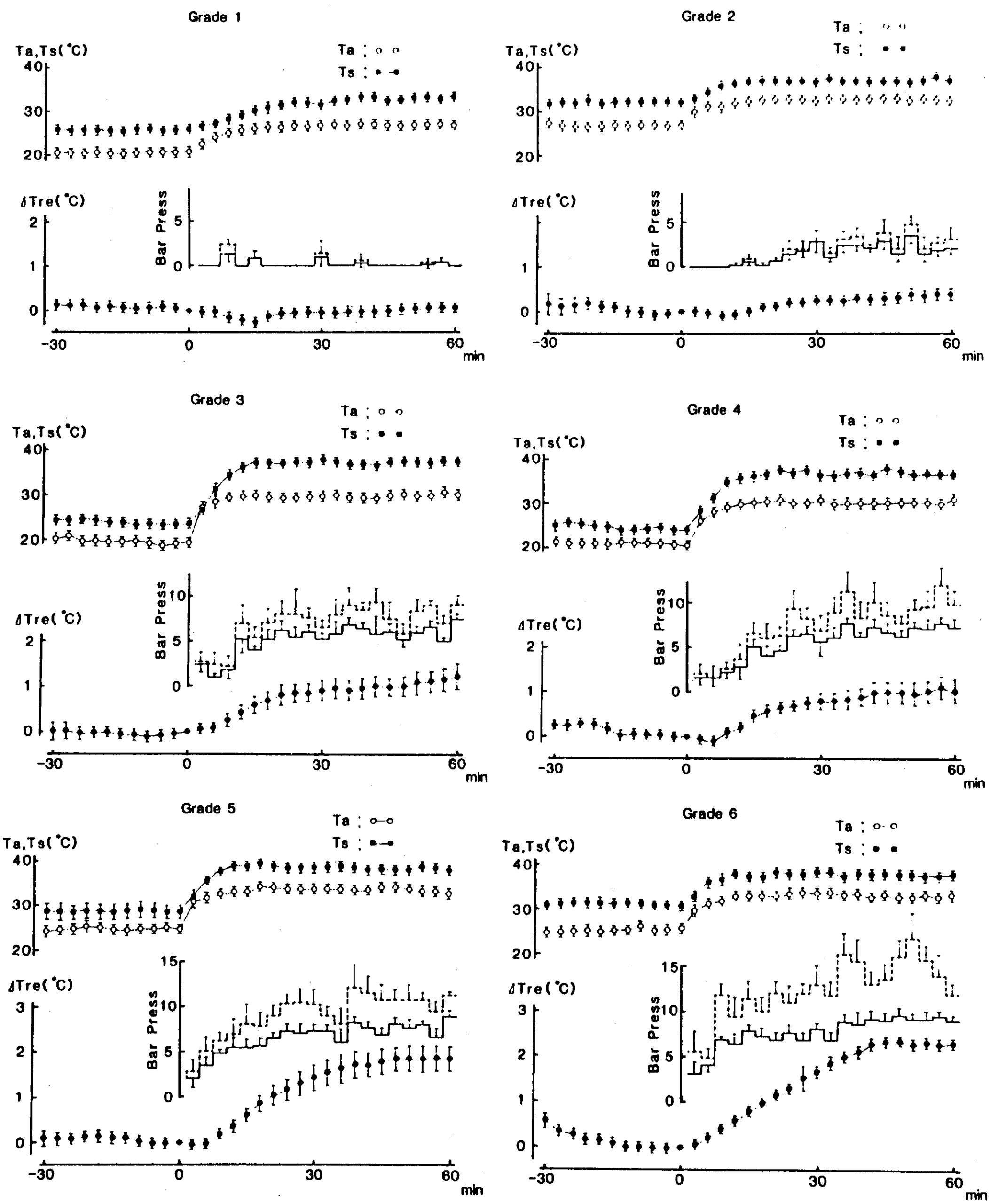

Fig. 2 Changes in the box (Ta), skin (Ts), rectal (ΔTre) temperature and the bar-pressing rate (Bar Press) of a group of six rats in six experimental conditions (Grade 1-6). Changes in Tre are expressed as deviation (ΔTre) from the base line Tre at the time zero. Solid lines indicate the reinforced bar-pressing rate, and dotted lines indicate the total bar-pressing rate which includes ineffective bar-pressing motions performed while the infrared lamp was off for a period of 8 sec.

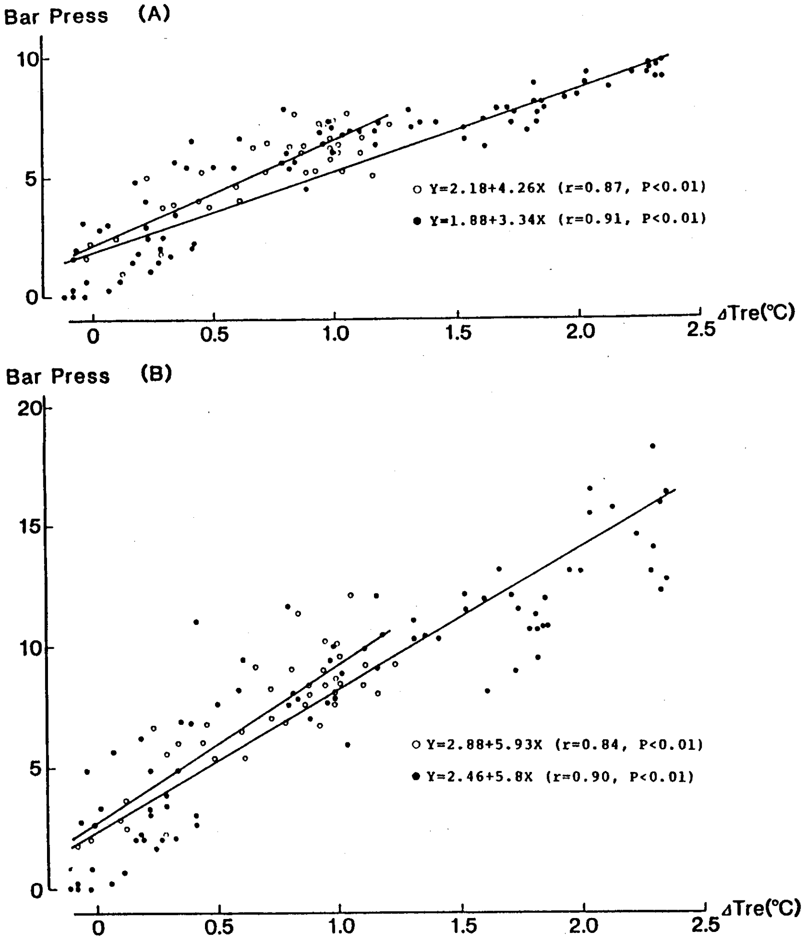

Fig. 3 The relation between the changes in the rectal temperature (ΔTre) and the bar-pressing rate (times/3 min). The plotted points of bar-pressing rates in Panel A and B represent the mean values of the reinforced rate and the total rate, respectively, in five groups. The data in which animals started to perform the operant behavior at 20 ± 1℃ (○) (Grade 3 and 4) and 27 ± 1℃ (●) of room temperature (Grade 2, 5, and 6) are shown.

rates were plotted against the mean values of temperatures of Tre, Ts and Ta obtained from five experimental groups (Grade 2-6). As shown in Fig. 3, the bar-pressing rate increases with an increment of the Tre. It is noticed that there is a close correlation ($P < 0.01$) between the degree of the increase of ΔTre and the bar-pressing rate. However, the initial ambient temperature did not affect this relationship.

Fig. 4 shows the relation between the bar-pressing rate and the Ts. The behavior started to increase significantly when the Ts increased above 35℃. Since the Ts is well controlled by heat-escape behavior, it never exceeded 38℃. In addition, there were no significant differences in the Ts controlled by the groups (Grade 3 and 4) in which animals were exposed from the initial temperature of 20 ± 1℃ and that by the groups (Grade 2, 5 and 6) in which animals were exposed from the initial temperature of 27 ± 1 ℃

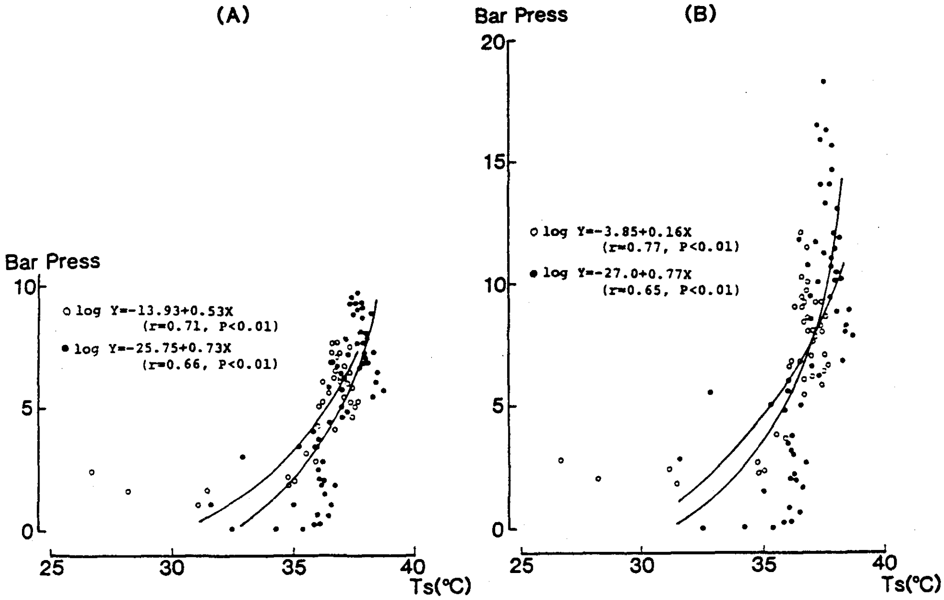

Fig. 4 The relation between the changes in the skin temperature (Ts) and the bar-pressing rate (times/3 min). The panels A, B, and symboles are as indicated in Fig. 3.

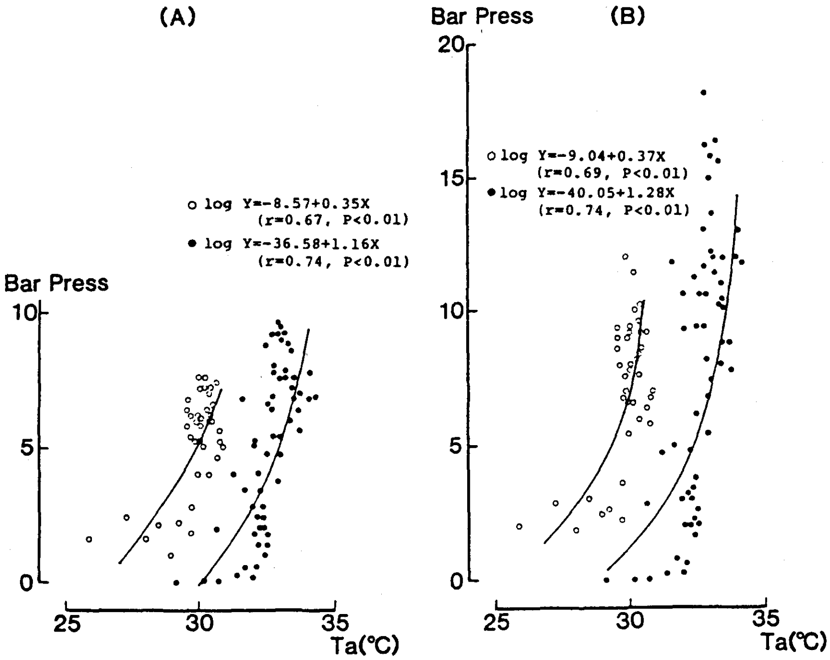

Fig. 5 The ralation between the box temperature (Ta) and the bar-pressing rate (times/3 min). The panels A, B, and symboles are as indicated in Fig. 3.

Fig. 5 shows the relation between the bar-pressing rate and the Ta selected by the behavior. The bar-pressing rate started to increase significantly when the Ta reached about 30℃, meanwhile the Ta was maintained between 30 and 35℃. It is interesting that the Ta selected by the behavior is significantly different ($P<0.01$) depending upon the initial room temperature. Animals exposed to the initial temperature of 20 ± 1℃ initiated to press the bar frequently when Ta reached to 30 ℃, so that Ta was kept constant at 30℃. On the other hand, animals exposed to the initial temperature of 27℃ started to press the bar frequently only after Ta reached to 32℃, and Ta was maintained below 33℃.

Discussion

When animals are exposed to various thermal environments, they maintain a stable core temperature through the behavioral and/or autonomic thermoregulatory responses[1,2,9]. When given an opportunity to select the ambient temperature, they operate heating and cooling devices so that thermal stress is reduced. Because the two means of thermoregulation, autonomic and behavioral, are interchangeable within certain limits, it is expected that the way of reducing the thermal load by either autonomic or behavioral mechanism will vary under different conditions.

In the present study, the animals have been learnt to perform the responses which are instrumental in causing a reduction in thermal stress of heat. It seems that the learned regulatory reponses will be performed with an amplitude proportional to the error signal drived from thermal load. Therefore, the bar-pressing rate at which the animals worked for reduction of the thermal load increased by increases in either the Ts or the Tre (Fig. 3 and 4). This means that both thermal inputs strongly contribute to the achievement of the behavioral thermoregulation against thermal stress.

The interaction of hypothalamic and skin temperature in thermoregulatory behavior has previously been reported[4-8], suggesting that when hypothalamus was directly cooled or heated, the behavioral regulation was accomplished in such a way that hypothalamic temperature remains fairly constant. In the present results, however, it is noticed that there is a close correlation between increases in Tre and bar-pressing rate during the whole experiments (Fig. 3). It is unknown why animals did not perform the operant behavior to keep their Tre constant, although they could have responded by increasing the rate of bar-pressing to prevent the increase of Tre. This indicates that thermal discomfort derived from error signals of Tre might be modulated by error signals of Ts[2,7,9].

A remarkable operant behavior was initiated when the Ts reached about 35℃ and gradually increased accompanied by a slight increase in Ts (Fig. 4). In contrast to Tre, Ts was well maintained below 38℃ by the behavioral regulation. This indicates that behavioral thermoregulation is strongly affected by the error signals derived from Ts as well as Tre, and that Ts is also one of the parameters that controls thermoregulatory behavior[2,7,9].

Concerning the ambient temperature as selected by the thermoregulatory behavior, it is revealed that behavioral responses were significantly induced at a Ta of above 30℃, and consequently, Ta was also controlled between 30-35℃ by behavior under a hot environment. Furthermore, in the present results, it is interesting that the selected Ta depended on the initial temperature at which the animals adapted before the exposure to various ambient temperatures, although no significant difference ($P>0.1$) was observed in the controlled Ts and Tre.

Previous reports suggest that the set points of body temperature are different during fever[10] or sleeping[11]. Considering these results, it is inferred that there will be the shifts in the set-point level of the central mechanism involved in the thermoregulatory behavior at different ambient temperatures. Based on the present results, it is apparent that the error signals generated by displacements of core or skin temperature, which are induced by external thermal load, cause a driving force for behavioral thermoregulatory responses. Also, in the magnitude of behavioral responses, there are close relationships among Ta, Ts and Tre. Moreover, the present results suggest that the initial ambient temperature before thermal load will be an important factor to determine the Ta selected by behavioral thermoregulation.

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