3-1968

Thermoregulation in a Cold Environment: Effects of Body Weight

Roger A. Kleinman
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Roger A. Kleinman entitled "Thermoregulation in a Cold Environment: Effects of Body Weight." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

Jasper Brener, Major Professor

We have read this thesis and recommend its acceptance:

William H. Calhoun, Joel F. Lubar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

March 1, 1968

To the Graduate Council:

I am submitting herewith a thesis written by Roger A. Kleinman entitled "Thermoregulation in a Cold Environment: Effects of Body Weight." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice President for
Graduate Studies and Research

THERMOREGULATION IN A COLD ENVIRONMENT: EFFECTS OF BODY WEIGHT

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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by

Roger A. Kleinman

March 1968

ACKNOWLEDGMENTS

The investigator would like to extend his appreciation to the chairman of his supervisory committee, Dr. Jasper Brener, for his counsel and patient assistance in the preparation of this thesis. Gratitude is also expressed to Dr. William H. Calhoun and Dr. Joel F. Lubar for their very helpful suggestions and criticisms.

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CHAPTER I

INTRODUCTION

The adjustment to a cold environment is a complex process involving varied physiological changes as well as certain adaptive behavioral maneuvers. Studies utilizing physiological measures of acclimatization often have been concerned with the assessment of metabolic or body temperature changes as a function of some sort of thermal stress (e.g., Brobeck, 1948; Fregly, 1953; Sellers, Reichman, Thomas, & You, 1951). More recently, however, operant behavior has been used as a measure reflecting the degree to which acclimatization has taken place. In these studies animals most often have been required to emit instrumental responses (level presses or pressure contact) to receive a burst of warm air (Carlton & Marks, 1958) or heat from an infra-red lamp (Baldwin & Ingram, 1967; Carlisle, 1966; Laties & Weiss, 1959; Revusky, 1966; Weiss, 1957; Weiss & Laties, 1961). Laties and Weiss (1960) subjected rats to continuous exposure in a cold environment (2° C.) for 30 to 41 days and found that during the postexposure training trials the exposed animals waited significantly longer than nonexposed controls before lever-pressing at a steady rate for infra-red heat reinforcement. The exposed animals also lost an average of 35 grams during the exposure period despite the fact that they had free access to food and water. Since ambient temperature was the manipulated variable, it appears that exposure to cold produced a marked change in the ability of the animals to maintain their weight at the pre-exposure level. Carlton and Marks (1957) have also found that during 10 days of continuous exposure to a cold environment (2° C.) rats did not maintain their body weight despite an increase in food intake as well as an elevation in lever pressing for bursts of warm air.

In contrast to the studies using continuous exposure, Revusky (1966) exposed animals to cold on a periodic basis. Hairless mice were allowed to press against a panel to receive a burst of heat from an infra-red lamp during each of 30 successive 6 hour sessions at 8.9° C. The results showed a decline in subaxilla temperature loss over the 30 days which could indicate acclimatization to the cold. There was also a decline in the number of heat reinforcements obtained per hour for the experimental sessions. The decrease in subaxilla temperature loss, then, was physiological in nature, reflecting enhanced body heat conservation, rather than being due to heat produced from an external source. A significant increase, however, in body weight over the 30 sessions was also obtained. Revusky suggested that the increase in body weight was unimportant to the process of acclimatization. This argument was based on experimental work by Sellers (1957) who found that animals exposed to cold (1-3° C.) increased food intake, reaching a plateau after about 10 days, but nevertheless weighed less than their controls kept at room temperature. The experiment described by Sellers (1957), however, subjected animals to prolonged exposure to cold, while in Revusky's study the animals lived at room temperature (24-26° C.) with free access to food and water during the time between their daily 6 hour sessions in the cold. When rats are exposed to a cold environment, increased body heat production is accompanied by a marked elevation of metabolic rate, oxygen consumption, and food intake (Brobeck, 1948; Fregly, 1953; Sellers, 1957). Higher temperatures (21-30° C.), conversely, are characterized by lower metabolic rates (Herrington, 1940), oxygen consumption (Sellers, 1957) and food intake (Brobeck, 1948). It can be assumed from these studies that periodic exposure to the cold would differentially affect weight level and that a gain in body weight after periodic exposure, therefore, cannot be ruled out as unimportant in influencing the course of acclimatization. Indicating that body weight affects behavioral adaptation to cold, Weiss (1957) found that undernourished animals in a cold environment obtain more heat in an instrumental heat reinforcement situation than their respective controls. It seems reasonable to assume that an increased layer of subcutaneous fat would be very effective in reducing body heat loss to subnormal external temperatures.

The present experiment, then, was conducted to ascertain the role of body weight in the physiological and behavioral adjustment to cold. Specifically, it was hypothesized that animals which gained weight after periodic exposure to cold would show a decreased temperature loss as well as less lever-pressing behavior for infra-red heat reinforcement than animals which were maintained at their pre-experimental weight level.

CHAPTER II

METHOD

Subjects

The subjects were 10 female, 6-1/2 month-old albino rats (Wistar Strain).

Apparatus

The five experimental chambers consisted of a rectangular milk-colored Plexiglas enclosure (6-1/2 x 7 x 9-3/4 inches) containing a Plexiglas lever. The lever was attached to a telegraph key which was fastened to the outside wall of the chamber. A 250 watt infra-red lamp suspended 10 inches above the floor of the chamber was activated for 3 seconds when the rat pressed the lever. Lever presses while the light was on had no effect upon the duration of the burst of heat. As soon as the light terminated, however, it could be reactivated by pressing the lever. The five chambers were placed in a cold room maintained at 8.9 ± 1° C. Since more than one experimental chamber was used at the same time, thermally insulating fiber board (36 x 36 inches) was placed between the chambers to shield adjacent enclosures against stray heat and light.

Procedure

Design. The 10 subjects were divided into two groups which were equated for body weight. Each rat was clipped the day preceding first placement in the cold and every three days thereafter. In order to control for day-night effects on the activity levels of the rats, one group was tested during the day, while the other was used at night. The day group consisted of 2 experimental and 3 control animals, while the night group contained 3 experimental animals and 2 controls. When the day group was tested, the cold room was illuminated by a white light. Since rats are assumed to be relatively insensitive to the red end of the spectrum, a red light was used for the night period. This procedure would not constitute a marked change as red light was used at night for these animals in the colony room prior to the experiment.

Training. All subjects were trained in the experimental chambers 6 hours daily for 18 successive days.

During these experimental sessions, the rats were given no food or water. After each session the subjects were returned to their individual cages in a colony maintained at approximately 22° C.

Measure of food intake. During this 18 hour intersession time, the control subjects were fed on an *ad lib* basis. The amount of food given the experimental subjects (controlled weight group) was apportioned so as to maintain their pre-experimental weight level. Both controlled weight and *ad lib* animals had free access to water. Body weight was measured before each experimental session. This procedure was followed, first, in order to determine any changes in weight after the animals had access to food, and secondly, to assess weight changes after a time period following which relatively normal metabolic rates had been attained (that is, in the absence of a thermal stress).

Measure of physiological acclimatization. Body temperature was measured before and after each experimental session in order to calculate intra-session temperature loss. This measurement was accomplished by placing a small disc-shaped thermistor on the skin lying over the rib cage underneath the upper right foreleg (subaxilla).

Measure of behavioral adaptation. Number of reinforcements obtained by each animal, as well as total number of lever presses, were counted for the daily 6 hour sessions in the cold.

CHAPTER III

RESULTS

Figures 1, 2, 3 and 4 illustrate the mean body temperature loss, mean reinforcements per hour, mean body weight change and mean food intake respectively for the controlled weight and *ad lib* groups over the 18 experimental sessions. Differences between means for the controlled and *ad lib* groups for these four effects were obtained from the last 5 sessions. Table 1 contains these differences and the respective *t* values. Note that the *ad lib* group had a greater food intake ($t = 7.42$, $p < .005$) and body weight increase ($t = 11.77$, $p < .005$). The *ad lib* group also showed a significantly ($t = 46.00$, $p < .005$) greater decrease in body temperature loss than the controlled weight animals. The decline in temperature loss between the first and last 5 sessions was significant ($t = 29.71$, $p < .005$), however, for the controlled group alone. Augmented metabolic rate may be responsible for this decreased temperature loss as the caloric intake of these animals during the last 5 sessions was significantly greater ($t = 1.98$, $p < .05$) than

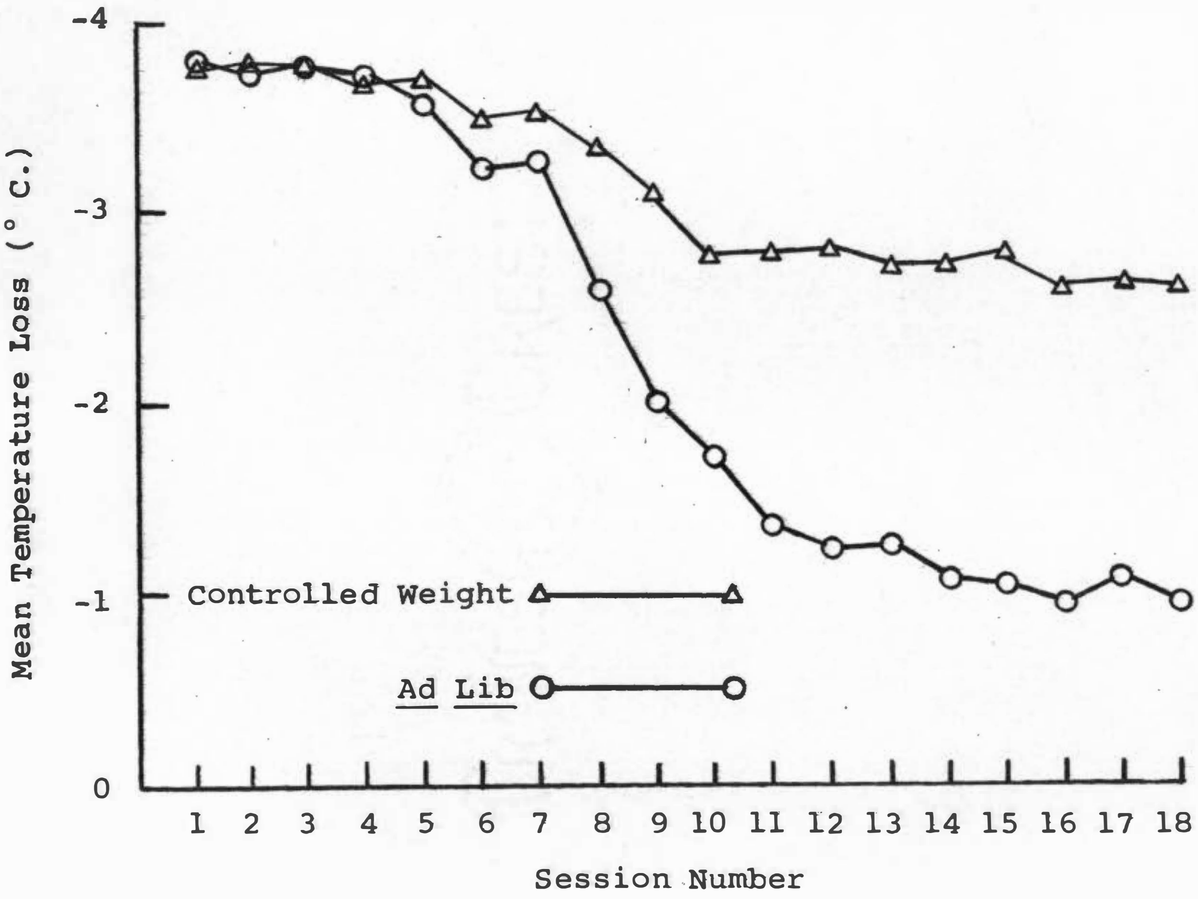

Figure 1. Mean body temperature loss over sessions in the cold.

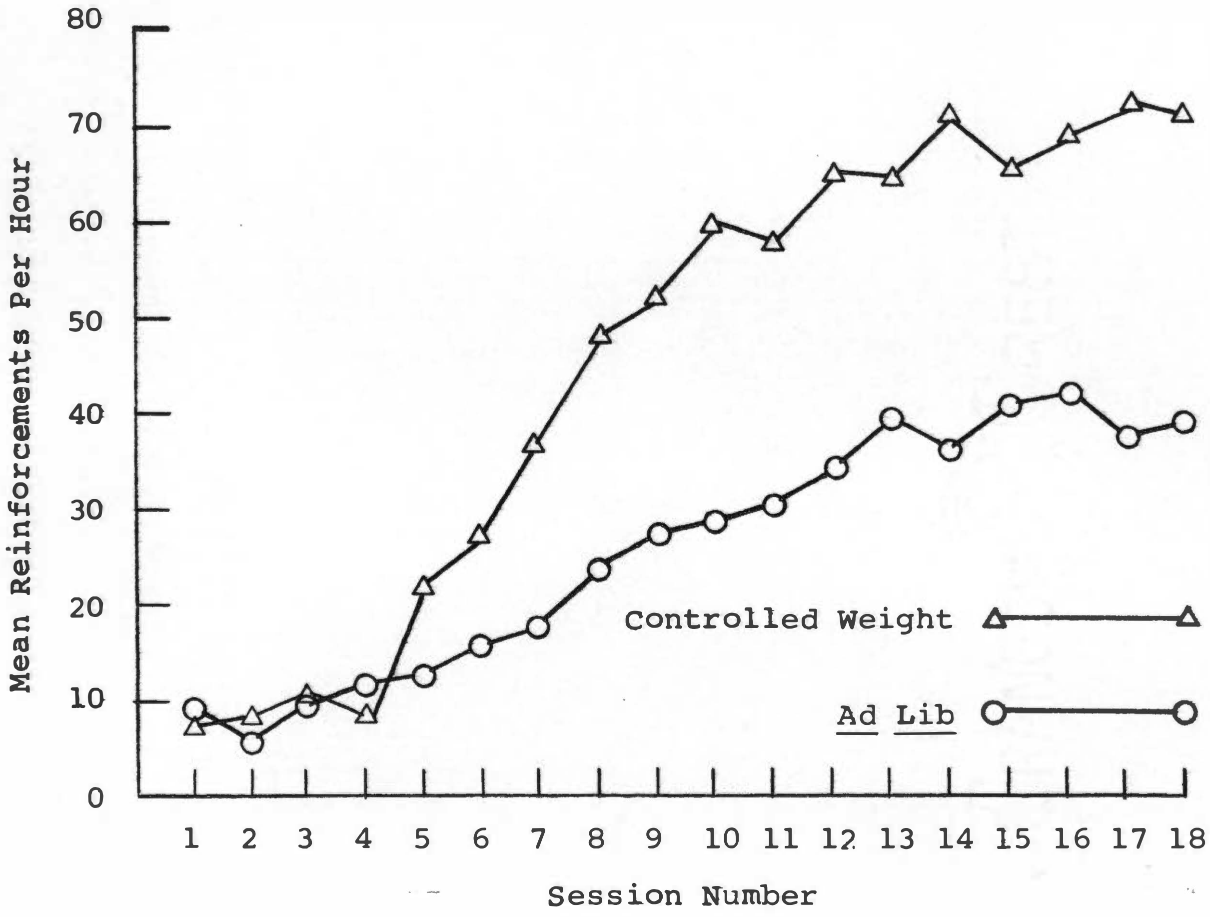

Figure 2. Mean reinforcements per hour over sessions in the cold.

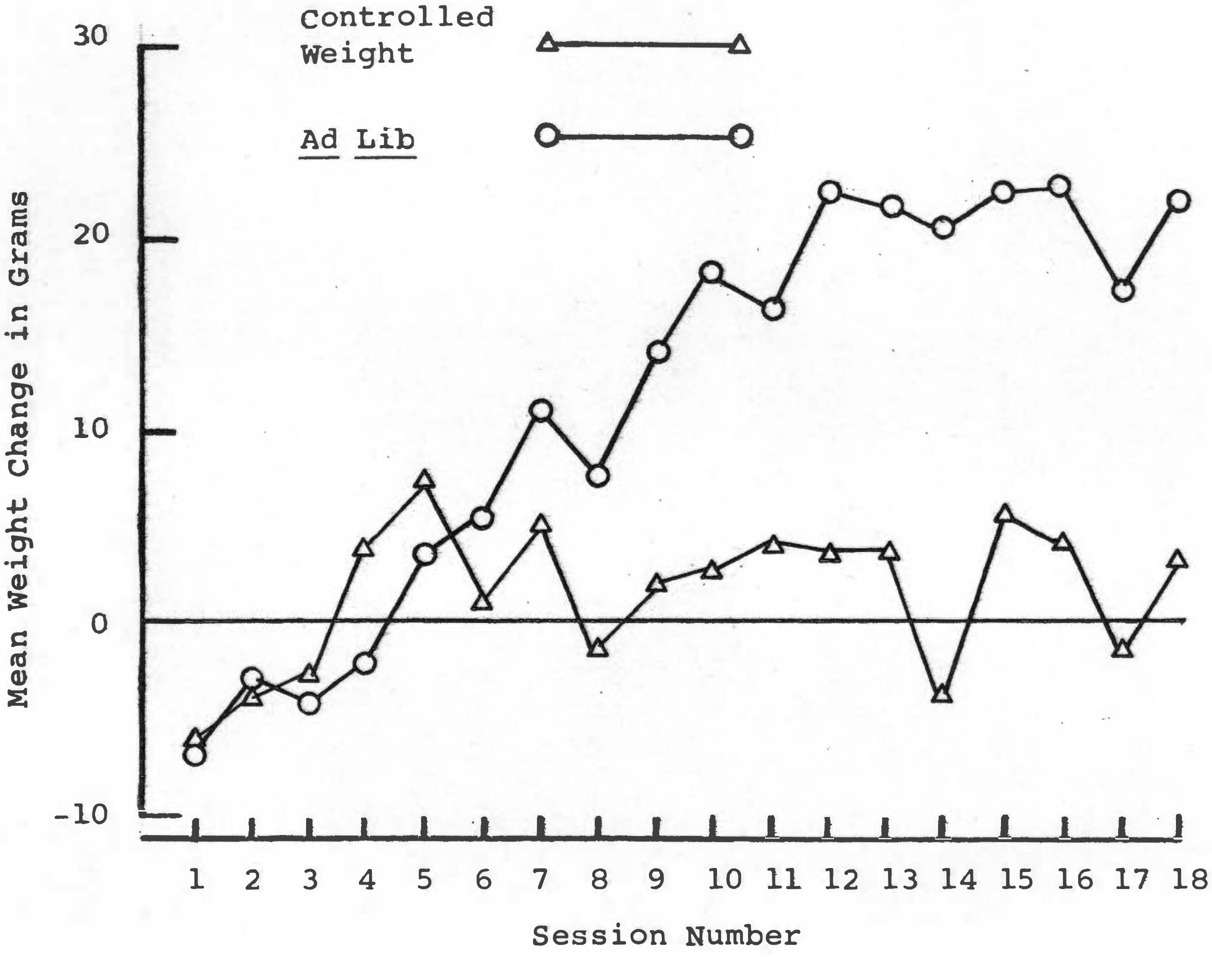

Figure 3. Mean body weight change over sessions in the cold.

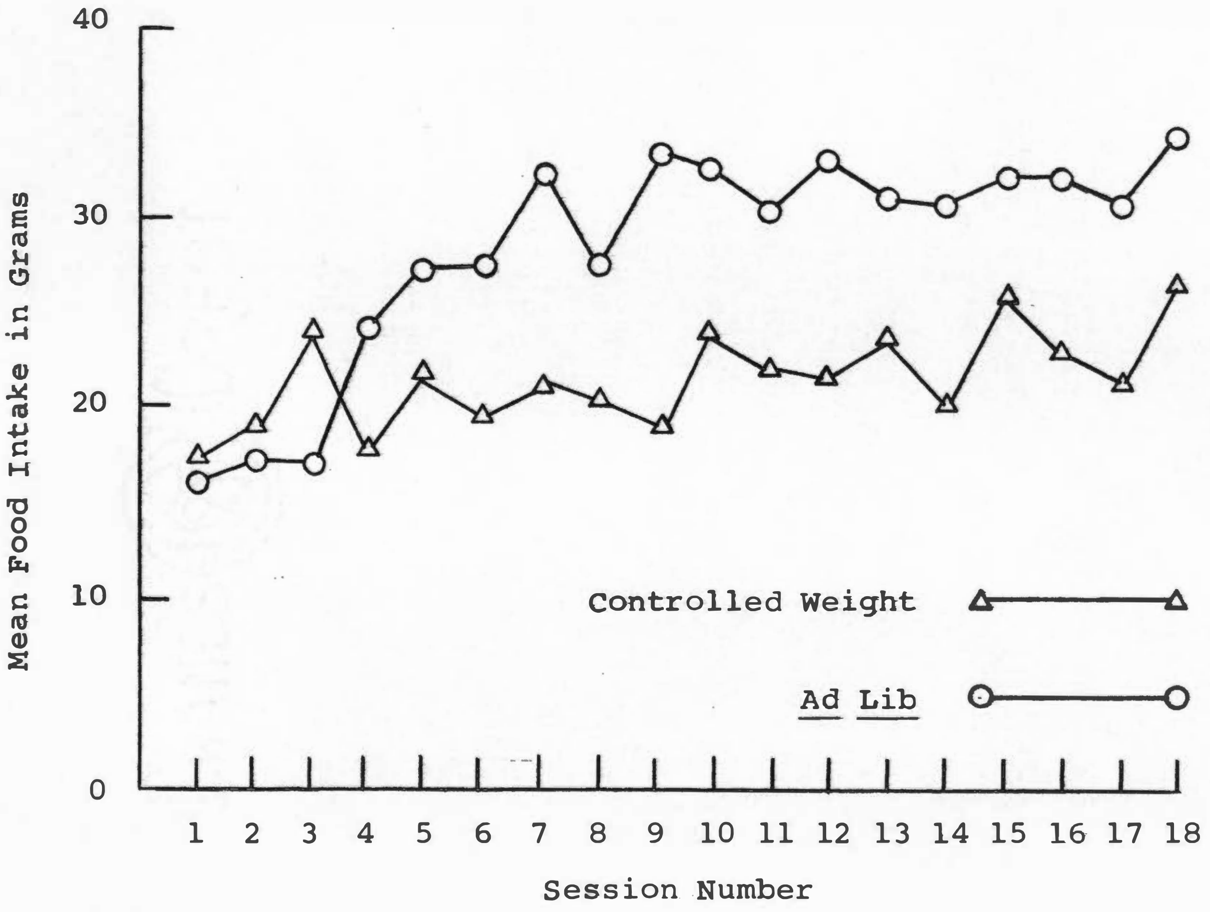

Figure 4. Mean food intake over sessions in the cold.

Table 1

Summary of Group Mean Differences and Respective t Values

Comparison	$\overline{X}_A - \overline{X}_C$*	df	t	p
Mean Temperature Loss	-1.61° C.	8	46.00	< .005
Mean Reinforcements Per Hour	-30.90	8	21.16	< .005
Mean Body Weight Change	20.48 gm.	8	11.77	< .005
Mean Food Intake	9.80 gm.	8	7.42	< .005

* $\overline{X}_A$ - mean for ad lib group.

$\overline{X}_C$ - mean for controlled weight group.

during the first 5 sessions. Their body weight, however, was maintained at the pre-experimental weight level.

It is argued that the insufficient ability of the controlled weight animals to physiologically acclimatize to the cold environment disposed them to engage in more behavioral adaptive maneuvers than the ad lib group who had laid down a greater fat deposit. The difference in mean number of reinforcements per hour between the controlled and ad lib groups was significant ($t = 21.16$, $p < .005$). The ad lib animals also exhibited a significant ($t = 19.72$, $p < .005$) increment in the mean number of reinforcements obtained per hour between the first and last experimental sessions.

The disparity which these two groups exhibited in their ability to adapt to a cold stress demonstrates the importance of body weight as a significant factor which can direct the course of physiological and behavioral thermoregulation. These results confirm the original hypothesis that animals which gained weight after periodic exposure to cold would show a greater degree of physiological acclimatization and less adaptive behavior than animals which were maintained at their pre-experimental weight level.

CHAPTER IV

DISCUSSION

The increased food intake (see Figure 4, page 13) displayed by the ad lib group fits well into the theory concerning thermoregulation proposed by Brobeck (1948, 1957). Amount of food consumed, he found, depended upon the temperature surrounding the organism. At low ambient temperatures food intake was high and gradually lessened as the temperature increased. An increment in body heat due to eating (specific dynamic action) was taken to support the proposition that animals eat to keep warm. As originally described by Rubner (1902), specific dynamic action (SDA) of food represented heat energy liberated by means of various side oxidative reactions which were secondary to the nutritive process. That this SDA is not produced via the work of ingestion or digestion was shown by Lusk (1912) who fed bones to dogs and found no related increases in heat production. Booth and Strang (1936) found in human subjects that a decline in eating and cutaneous vasodilation were correlated and that with subjects of normal body weight satiety was complete with an increase of 0.9° C. at the surface of the skin. Heat energy liberated via nutritive metabolic processes would not appear to account for this finding since satiety occurred only 22 minutes after eating had begun. Strominger and Brobeck (1953) reported other evidence which suggested an independence of body heat production due to food ingestion (SDA) and heat energy in the form of caloric content normally released later in the metabolic process. These investigators presented diets high in either protein, carbohydrate or fat content to their animals. Food intake was regulated not by caloric content, but consistently by the SDA of the diets.

These studies show that the increase in body heat production due to feeding can control amount of food consumed, and strongly suggest that eating may indeed be considered a thermoregulatory response which functions to keep an animal warm, especially in a cold environment.

In the present experiment, all the animals were given access to food after each session in the cold. They ate voraciously at first, gradually diminishing their rate of food intake. The *ad lib* animals ingested more food than was required for them to maintain a constant body weight (see

Figure 4, page 13). Their food intake showed a marked increase during the first 10 sessions, and began to level off thereafter. It should be noted that body temperature loss (see Figure 1, page 10) for these animals also began to level off at about session 11. The fact that the food intake of the *ad lib* animals exceeds that required for normal body weight maintenance, but is directly related to temperature loss suggests that their increased food intake was a thermoregulatory response to the previous 6 hours in the cold, and according to Brobeck's theory served to keep them warm.

Prolonged increases in metabolic rate due to continuous exposure to cold prevent increases in body weight despite elevated food intake (Carlton & Marks, 1957; Sellers, 1957). The fact that the *ad lib* animals gained weight, however, suggests that their metabolic rates during the 18 hour intersession periods (at room temperature) had decreased to a level such that their increased food intake was superfluous to their energy requirements. This conclusion seems warranted since it is known that metabolic rates increase at low ambient temperatures and decrease again when animals are exposed to room temperatures (Herrington, 1940; Sellers, 1957). This finding emphasizes the importance of considering periodic versus continuous exposure to cold as an important factor which may differentially affect body weight changes.

Although body weight was found to play a significant role in the process of thermoregulation, it must be noted that body weight alone is by no means the sole determinant of this process. The controlled weight animals were maintained at their pre-experimental weight level, but nevertheless exhibited an increased ability to conserve body heat as evidenced by the decrease in heat loss over the experimental sessions (see Figure 1, page 10). This ability alone was not, however, sufficient to produce complete adaptation to the cold, as these animals exhibited a considerable amount of instrumental behavior which was directed towards producing heat from an external source (see Figure 2, page 11). Although the *ad lib* animals gained more weight and showed a significantly greater reduction in body temperature loss, they nevertheless displayed a significant increment in this instrumental adaptive behavior. Neither group relied strictly upon body weight in their efforts to adapt to the cold stress, but when presented with the opportunity to manipulate their environment, they rapidly took advantage of the contingency. These results emphasize a sometimes forgotten and important point: the adaptation of an organism to changes in its internal or external environment is not governed independently by either a physiological or behavioral process. Interacting intimately with each other, these two processes must be considered as a single system which produces the conditions by which an organism may function economically as a whole.

CHAPTER V

SUMMARY

The present study investigated the effects of body weight on the physiological and behavioral adjustment to a cold stress. Ten rats were periodically exposed to a cold environment (8.9° C.), 6 hours per day for 18 successive days. The food intake of 5 of these animals was restricted so as to maintain their pre-experimental body weight (controlled weight group). The remaining 5 rats were put on an *ad lib* diet and gained significantly ($p < .005$) more weight than the experimental animals. The controlled weight group exhibited a decreased ($p < .005$) ability to physiologically acclimatize to the cold, while showing an increased ($p < .005$) amount of behavior directed towards obtaining heat from an external source. These results supported the original hypothesis that body weight is a prominent factor which influences the thermoregulatory process. Differences between periodic versus continuous exposure to the cold were discussed, and it was concluded that these two experimental procedures produce important differences in metabolic rate, food intake, and body weight. Physiological acclimatization and behavioral adaptation were shown to be nonindependent processes, but intimately related as a single system in governing the course of thermoregulation.

BIBLIOGRAPHY

BIBLIOGRAPHY

Baldwin, B. A. and Ingram, D. L. Behavioral thermoregulation in pigs. *Physiol. & Behav.*, 1967, *2*, 15-21.

Booth, G. and Strang, J. Changes in temperature of the skin following the ingestion of food. *Archs intern. Med.*, 1936, *57*, 533-543.

Brobeck, J. R. Food intake as a mechanism of temperature regulation. *Yale J. Biol. Med.*, 1948, *20*, 545-552.

Brobeck, J. R. Neural control of hunger, appetite, and satiety. *Yale J. Biol. Med.*, 1957, *29*, 565-574.

Carlisle, H. J. Heat intake and hypothalamic temperature during behavioral temperature regulation. *J. comp. physiol. Psychol.*, 1966, *61*, 388-397.

Carlton, P. L. and Marks, R. A. Heat reinforced operant behavior as a function of prolonged cold exposure. *USA Med. Res. Lab. Rep.*, 1957, No. 325, 9p.

Carlton, P. L. and Marks, R. A. Cold exposure and heat reinforced operant behavior. *Science*, 1958, *128*, 1344.

Fregly, M. J. Minimal exposures needed to acclimatize rats to cold. *Am. J. Physiol.*, 1953, *173*, 393-402.

Herrington, L. P. Heat regulation of small laboratory animals. *Am. J. Physiol.*, 1940, *129*, 123-129.

Laties, V. G. and Weiss, B. Thyroid state and working for heat in the cold. *Am. J. Physiol.*, 1959, *197*, 1028-1034.

Laties, V. G. and Weiss, B. Behavior in the cold after acclimatization. *Science*, 1960, *131*, 1891-1892.

Lusk, G. Animal calorimetry. The influences of the ingestion of amino acids upon metabolism. *J. biol. Chem.*, 1912, *13*, 155-184.

Revusky, S. H. Cold acclimatization in hairless mice measured by behavioral thermoregulation. Psychonom. Sci., 1966, 6, 209-210.

Rubner, M. Die Gesetze des Energieverbrauchs bei der Ernährung, Leipzig, 1902.

Sellers, E. A. Adaptive and related phenomena in rats exposed to cold. A review. Revue can. Biol., 1957, 16, 175-188.

Sellers, E. A., Reichman, S., Thomas, N., and You, S. S. Acclimatization to cold in rats: Metabolic rates. Am. J. Physiol., 1951, 167, 651-655.

Strominger, J. L., and Brobeck, J. R. A mechanism of regulation of food intake. Yale J. Biol. Med., 1953, 25, 383-390.

Weiss, B. Thermal behavior of the subnourished pantothenic-acid-deprived rat. J. comp. physiol. Psychol., 1957, 50, 481-485.

Weiss, B. and Laties, B. G. Behavioral thermoregulation. Science, 1961, 133, 1338-1344.