THE EFFECT OF HIGH AMBIENT TEMPERATURE ON TIMING BEHAVIOR IN RATS¹

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The present experiments demonstrated a reliable within-session increase in rectal temperature (T_{re}) at 25° C during stable differential-reinforcement-of-low-rate (DRL) performance. The thermal response was found to be independent of the DRL value and reinforced DRL performance, but dependent on the state of the animal's deprivation. Exposure to a 35°-C environment increased the post-session T_{re} significantly above the 25°-C post-session T_{re} for seven of eight subjects. Response and reinforcement rate at 35° C was found to be independent of DRL value, although it decreased as DRL value increased at 25° C. A discriminative stimulus used to mark the end of the interval increased the reinforcement rate at 25° C but provided no advantage at 35° C. Measurement of the pattern of responding during DRL performance revealed increases in the proportion of long interresponse times at 35° C. Reinforcement rate was found to decrease progressively at 35° C, reaching a minimum within 40 to 50 min of the 90-min session. Visual observation of overt behaviors during DRL performance at 35° C revealed a reduction in the frequency of overt behavior, characteristic of 25°-C performance, and a time-dependent increase in the probability of an alternative set of behaviors.

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Discussion

Few studies have been reported on the effect of high ambient temperature on schedule-controlled behaviors. Hamilton and Brobeck (1964) report decrements in food reinforced fixed-ratio performance at 35° C, while Barofsky and Hurwitz (1968) reported

no decrement in discriminated shock avoidance at 35° C. The present experiments extended these observations to include the effect of high ambient temperature on behavior maintained by the differential-reinforcement-of-low-rate (DRL) schedule of reinforcement (Ferster and Skinner, 1957; Wilson and Keller, 1953).

The available evidence suggests that responding, food consumption, and spontaneous motor activity are maintained at a lower rate at 35° C (Hamilton, 1963; Hamilton and Brobeck, 1964; Stevenson and Rixon, 1957). It might be expected, therefore, that behavior dependent on a schedule of reinforcement which resulted in a low rate of responding and low food-reinforcement rate would not be adversely affected by high ambient temperature exposure. The DRL schedule of reinforcement yields such behavior and, by appropriate selection of the schedule value, also provides a means of determining the response and reinforcement rate at which performance at 35° C will not decrease.

METHOD

Subjects and Deprivation Procedure

Fourteen male Sprague-Dawley (Charles River) rats, initially weighing 200 to 250 g, served as subjects. Six served as normally grow-

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ing controls, and four served as experimental subjects in each of two experiments. In both experiments, the adjusted percentage deprivation procedure was used. The six control animals provided an estimate of free-feeding body weight and the experimental animals were maintained at 70 or 80% of this weight by post-session food supplements. Water was not available in the experimental chamber but was freely available at the home cage.

Apparatus

Training in both experiments occurred in the same two-lever operant chamber, in which only one lever was operable. The lever contact closed with a static weight of 20 g. An indicator light marked the operative lever and served as a discriminative stimulus (see below). The reinforcer was a 45-mg Noyes food pellet. Solid state modules scheduled DRL reinforcements and recorded responses on separate counters and on a cumulative recorder. The chamber was placed in an insulated wooden box and white noise within the chamber masked exterior noises. The chamber was housed in an environmentally controlled room. A fan provided adequate air circulation (12 cfm) between the environmental room and the chamber. The animals and the chamber were housed together in the same environmental room.

Interresponse times (IRTs) in 3-sec intervals were collected on 10 Sodeco counters during DRL 15-sec training in Exp. 2d. Each counter measured successive 3-sec intervals, with the last counter recording all IRTs greater than 27 sec.

Procedure

DRL training. The animals in Exp. 1 were trained at DRL 15-, 20-, 25-, 30-, and 100-sec, while the animals in Exp. 2 were trained at DRL 15- and 30-sec. Two different discriminative stimulus conditions were used. In the S^D -Reinforcement condition, a light over the lever was scheduled to go off briefly and immediately come back on after a reinforced response. The S^D -Reinf. functioned as a hopper light would to indicate the occurrence of a reinforcement. In the S^D -Interval condition, the light over the lever was scheduled to go off at the end of the DRL interval and to remain off until a response occurred. For both S^D conditions, the light came on after

a reinforced response and did not go off for an unreinforced response.

The animals were trained under both S^D conditions in Exp. 1 but only on the S^D -Reinf. condition in Exp. 2.

Body and ambient temperature condition. Rectal temperatures (T_{re} s) were taken immediately before and after a session. Temperatures were measured on a tele-thermometer (YSI model 43TD) in Exp. 1 and on a United Systems Corporation digital thermometer (Model 502-3) in Exp. 2 by a small mammal rectal thermister (YSI Model 402) inserted 8 to 10 cm beyond the anal sphincter.

The ambient temperature of the environmentally controlled room was kept at 25° C or 35° C $\pm$ 1° C with a 40 to 50% relative humidity. The evening before 35°-C exposure, the animals were removed from the environmental room and placed in an adjacent area. Temperature regulation of this area was not possible and varied from 22 to 28° C. The temperature of the environmental room was increased to 35° C and the chamber allowed to come to thermal equilibrium with the 35°-C environment. During the experimental session, at 25 or 35° C, measures of the temperature within the chamber were found to be the same as in the environmental room, with no increment in ambient temperature during the session. The evening of the day of 35°-C exposure, the animals were returned to the environmental room, which was now cooled to 25° C.

EXPERIMENT 1

Staddon (1965) demonstrated that training at a particular DRL value facilitates performance at other values. For this reason, the animals in the present experiment were first trained until a stable rate of responding occurred at DRL 30-sec. They were then trained over a wide range of DRL values (*i.e.*, DRL 15- to 100-sec) during which time they were periodically tested at 35° C. The S^D -Interval condition was introduced to provide an alternative means of facilitating timing behavior, and thereby increase the frequency of reinforcement at a particular DRL value (Segal-Rechtschaffen, 1963).

Procedure

Deprivation and training. The body weights of the four experimental animals were

reduced by restricting daily food intake. Approximately four weeks were required until the slower growing experimental animals were 80% of the body weight of the control animals. At this point, both DRL training and increased supplementary post-session feeding were started. Training consisted of the differential reinforcement of responses which approximated a lever press. Once the lever-press response was firmly established (after 50 reinforcements), the animals were placed on a DRL 5-sec schedule. This was followed by three or four 1-hr sessions at DRL 10-sec, ten or eleven 90-min sessions at DRL 15-sec, and thirty 90-min sessions at DRL 30-sec.

Testing conditions. Table I summarizes the order and number of training sessions at each DRL value and S^D condition studied in Exp. 1. The animals were trained at DRL 15-, 20-, 25-, 30-, and 100-sec at the S^D-Reinf. condition and at DRL 15- (only animal G-7), 25-, and 100-sec at the S^D-Interval condition.

Originally, progression from one DRL condition to another was based on the animals' meeting a criterion of two or fewer responses per reinforcement and maintaining a stable response rate over sessions. It was soon clear, however, that not all animals would meet this criterion for the S^D-Reinf. conditions, although all did for the S^D-Interval conditions. To increase confidence in the observations, three of the four animals were given repeated 35°C exposures at DRL 20- and 25-sec and extended training at DRL 100-sec (at the

S^D-Reinf. condition). Animal G-7 was able to meet the criterion of stable performance and was therefore given somewhat less training per test condition (Table I). Comparison of animal G-7's performance with the other animals provided a check on the internal consistency of the data.

A "work week" typically consisted of a six-session period with baseline data at 25°C being collected Monday to Thursday, 35°C exposure on Friday, and the reversibility of the 35°C exposure assessed on Saturday again at 25°C. An experimental session lasted 90 min under all conditions. Violations which led to less than the six-day work week period occurred twice, only for animal G-7, and were due to 35°C exposure scheduling problems. Standardization of the 35°C exposure interval led to variation in the maximum possible frequency of reinforcements per DRL condition but was unavoidable if rectal temperature changes were to be compared on the same time base.

Rectal temperatures were taken for every training session during the initial training at DRL 15- and 30-sec. When the animals were tested at the various DRL values, T_{res} were taken pre- and post-session only for the session-before, session-of, and session-after the 35°C exposure.

RESULTS

Initial training. Efficient DRL 15-sec responding developed within five to six sessions for all animals, with response rate reducing

Table 1

Order and number of training sessions at each DRL value and S^D-condition studied in Exp. 1.

Animal G-7				Animals G-8, 11 & 12			
S ^D -Conditions	DRL (in sec)	Sessions		S ^D -Conditions	DRL (in sec)	Sessions	
		25° C	35° C			25° C	35° C
S ^D -Reinf.	15	11		S ^D -Reinf.	15	11(10)*	
	30	38	2		30	38	2
	15	5	1		15	5	1
	20	14	1		20	22	4
	25	7	1		25	25	5
	30	10	3				
S ^D -Interval	15	8	2	S ^D -Interval	25	20	4
	25	5	1		100	18	1
S ^D -Reinf.	100	10	1	S ^D -Reinf.	100	40(28)*	1(0)*
S ^D -Interval	100	12	2				
TOTAL		120	14			179	18

*G-12.

to approximately four responses per minute and reinforcements per session increasing to approximately 200. Shifting the animals to DRL 30-sec decreased the response rate from four to approximately 2.5 responses per minute. This decrease occurred within the first 10 days of training and remained relatively stable throughout the 30-day period. The frequency of reinforcements stabilized at fewer than 100 per session.

The effect of high ambient temperature on DRL performance. Animal G-12 died due to an accidental overheating of the environmental room at DRL 100-sec (S^D -Reinf.). Figure 1 is a plot of the response rate as a function of the various DRL values. The data for the session-before, session-of, and session-after 35°C exposure, for the last test at each DRL value, were plotted as best estimates of stable performance independent of an indi-

vidual animal's success in meeting the criterion of stable performance (see above). Response rates for all animals on the session-before and session-after 35°C exposure were similar, thus demonstrating that 35°C exposure did not irreversibly affect response rate. For all animals, the response rate was inversely related to DRL value at 25°C .

Exposure to 35°C resulted in a relatively constant response rate as a function of DRL value. The difference between the response rate at 25°C and 35°C decreased as DRL value increased. The presence of the S^D -Interval condition neither substantially enhanced the response rate at 25°C , nor moderated the effects of the high ambient temperature exposure (Fig. 1). The reliability of the effect of the 35°C exposure on the response rate was assessed for three animals (G-8, 11, and 12) by repeated exposures to the 35°C

Fig. 1. Responses per minute are plotted as a function of DRL value, three-session exposure sequence, S^D condition, and animal. The half-closed circle represents data which overlapped sufficiently so that it was not possible to display each point separately.

environment at DRL 20-sec and DRL 25-sec (see Table I). For the 39 exposures (13 per animal) in question, the highest response rate at 35° C was 40% below that of the response rate at 25° C.

Figure 2 is a plot of reinforcements per session for the same data plotted in Fig. 1. Inspection of the figure reveals that the reinforcement rate decreased as DRL value increased at 25° C. Comparison of session-before and session-after 35°-C exposure revealed that high ambient temperature did not irreversibly affect reinforcement rate. Rarely, if ever, were unconsumed food pellets found in the food cup after 35°-C exposure. With the exception of animal G-8, in the S^D-Reinf. condition, the reinforcements per session at 35° C appeared relatively constant across DRL values. The S^D-Interval condition increased the reinforcement rate at 25° C relative to the S^D-Reinf. conditions for both DRL 25- and 100-

sec performance. At 35° C the reinforcement rate appears relatively constant across DRL values and essentially the same as was found in the S^D-Reinf. condition.

Figure 3 is a plot of the mean reinforcements per minute each animal produced at DRL 30-sec (S^D-Reinf. condition) with the experimental session divided into nine 10-min segments (equivalent response-rate data were not available). As can be seen, the frequency of reinforcement over the session remained fairly stable at 25° C. At 35° C, the frequency of reinforcements at first remained comparable to that observed at room temperature, but after 40 to 50 min, decreased to a noticeably lower level. Thus, it appears that the decreases in reinforcement rate (Fig. 3) at 35° C varied as a function of time in the heat. The data at other DRL values were comparable to those illustrated in Fig. 3 for DRL 30-sec.

S^D CONDITIONS

Fig. 2. Reinforcements per session plotted as a function of DRL value, three-session exposure sequence, S^D condition, and animal. The half-closed circle represents data which overlaps sufficiently so that it was not possible to display each point separately.

In summary, it appears that the effect of 35°-C exposure on DRL performance was to reduce the response rate, decrease the reinforcements received per session, and decrease the number of reinforcements received over time. The response rate and reinforcements per session observed at 35° C remained fairly constant as DRL value increased.

The thermal response of the animal as a function of DRL value and ambient temperature. Figure 4 plots the pre- (open squares) and post- (closed circles) session T_{re} s for the initial training at DRL 30-sec and each DRL test condition included in Fig. 1. The training data (B) plotted consist of the mean, plus or minus two standard deviations (± 2 S.D.s), for 29 of the 30 days of training at DRL 30-sec (data for one training day were dropped due to apparatus problems). The mean post-session T_{re} increased above the pre-session T_{re} for all animals. Variability of T_{re} in the post-session was reduced for all four animals. Inspection of Fig. 4 suggests that the pre- and

post-session T_{re} s at DRL 30-sec (B) for animal G-12 were not different. However, a t-test performed on the difference between pre- and post-session T_{re} s for animal G-12's data revealed a significant difference ($t = 3.40$; $df = 29$; $P < 0.01$).

The pre- and post-session T_{re} s for each three-day ambient temperature exposure sequence are plotted in Fig. 4 as a function of DRL size and S^D condition. As can be seen, both the pre- and post-session T_{re} s remain reasonably within ± 2 standard deviations of the baseline pre-session T_{re} s at 25° C, thus demonstrating no differential effect on T_{re} by the DRL value. The post-session T_{re} s for the 35°-C exposures were significantly above the 25°-C exposures for three of the four animals, and this increase in post-session T_{re} appeared independent of the DRL value.

A review of the data revealed that for animal G-12, only one out of a total of seventeen 35°-C exposures significantly increased post-session T_{re} s. On the other hand, 14 out of the total of fourteen 35°-C exposures for animal G-7, 17 out of the total of eighteen 35°-C exposures for animal G-8, and 13 out of the total of eighteen 35°-C exposures for animal G-11 resulted in post-session T_{re} s which were significantly different from the baseline post-session T_{re} s.

To summarize, a within-session increase in T_{re} s was observed to occur for all animals and was found not to vary as a function of DRL value or presence or absence of a discriminative stimulus. Exposure to a 35°-C environment significantly increased post-session T_{re} s relative to 25° C for three of the four animals.

DISCUSSION

Response and reinforcement rate at 25° C decreased as DRL value increased, thus replicating the findings of Wilson and Keller (1953). Response and reinforcement rate appeared independent of DRL value at 35° C. The S^D -Interval condition increased the reinforcement rate but not the response rate at 25° C. In contrast, the response and reinforcement rate at 35° C for the S^D -Interval condition was comparable to the S^D -Reinf. condition (Fig. 1 and 2).

A consistent within-session increase in T_{re} was observed, although variation in DRL value did not affect the magnitude of the

Fig. 3. The mean reinforcements per minute at DRL 30-sec (S^D -Reinf. condition) are plotted as a function of nine 10-min segments for each animal. The data plotted at 25° C consist of the mean of the session-before and session-after 35° C exposure.

S^D CONDITIONS

Fig. 4. Plotted are the pre- (open squares) and post-session (filled circles) T_{re} s as a function of DRL value, ambient temperature, S^D condition, and animal. Baseline (B) measures consist of the mean pre- and post-session T_{re} s plus or minus two standard deviations for 29 training sessions at DRL 30-sec (S^D-Reinf. condition). The sequence of three connected points at each DRL value represents the session-before, session-of, and session-after 35°C exposure for pre- and post-session measures (see animal G-8's panel). Post-session T_{re} s above the dashed line differ significantly from baseline post-session T_{re} s.

thermal response. For three of the four animals, exposure to a 35°C environment significantly increased post-session T_{re} above that observed for the post-session T_{re} in a 25°C environment.

Thus, contrary to expectation (see Introduction), response rate at 35°C decreased as readily for behavior maintained by a schedule of reinforcement which generated a low response rate, as for a schedule of reinforcement

which generated a high response rate (*i.e.*, FR performance; Hamilton and Brobeck, 1964). In both the present experiment and the Hamilton and Brobeck experiment, performance at 25°C resulted in a within-session increase in T_{re} and in both, performance was maintained by food reinforcement. Whether the observed decrements in performance at 35°C reflect anorexia or a response to hyperthermia cannot be determined from the present ex-

periment. A second experiment did, however, provide the necessary information to distinguish between these alternatives.

EXPERIMENT 2a

It was not clear from Exp. 1 whether the observed within-session increase in T_{re} was dependent on adjustment to the deprivation procedure or on DRL training. For this reason, the thermal response during each component of the deprivation procedure was studied separately.

Procedure

The subjects were four male experimentally naive Sprague-Dawley rats. For the first two weeks of the experiment the animals were simply removed from their home cage, handled, and returned to the home cage. For the next 11 consecutive sessions T_{re} s and weights were taken before and after a 1-hr session, which the animals spent in their home cage. During this period, the animals had free access to food and water. Following the T_{re} and weight measures on the eleventh day, all food was removed from the animals.

The five days before deprivation began were utilized to estimate the free-feeding body weight for each animal. Deprivation was continued until the weights of the animals reduced to 70% of their mean free-feeding body weight. Deprivation consisted of restricting the food given the animals to 5 g or less per day. Approximately 15 days were required until the body weight of the animals reached the prescribed level. Next, the animals were maintained for a period of seven days at the 70% weight. This was followed by an increase in the amount of supplementary post-session food, so that body weight increased at the rate of the control group. This was continued for a seven-day period. Rectal temperatures were taken, as before, only before and after a 1-hr session. The second T_{re} measure in this and during all other portions of the experiment was taken before the animals were given post-session food.

Following resumption of growth by increased post-session food supplements, the animals were placed in the chamber for a 90-min period to determine their operant level of responding. This procedure continued for five sessions (seven days). Next, the food dis-

persing mechanism was made functional so that any lever press produced a food reinforcer. No shaping of the animals was performed.

RESULTS

Figure 5 plots the pre- and post-session T_{re} s for each animal during *ad-libitum* feeding, deprivation, maintenance of the 70% body weight, increased food supplementation, operant-level determinations, and the first five training sessions at DRL 15-sec.

Inspection of Fig. 5 reveals no consistent within-session increases in T_{re} during *ad-libitum* feeding or during deprivation. An increase of 0.2°C (0.5°F) or greater was used

Fig. 5. Pre- (open square) and post-session rectal temperatures plotted as a function of *ad-libitum* feeding, deprivation, maintenance at the 70% body weight, increased supplementary post-session feeding, operant level, and DRL 15-sec training for each animal.

as the criterion of a within-session increase in T_{re} . The thermal response begins to occur during the period of maintenance at the 70% body weight for some animals and becomes increasingly likely during the increased food supplementation period, operant level determinations, and DRL 15-sec training. It is not clear from the data, however, whether the thermal response was due to a reduction in pre-session T_{re} or to an increase in post-session T_{re} . The observation of the consistent separation in within-session T_{re} before DRL training suggests that the thermal response was dependent on deprivation procedure rather than on existence of timing behavior.

EXPERIMENT 2b

The results of Exp. 1 clearly demonstrated that increases in the DRL value did not modify the within-session increase in T_{re} . In the present experiment, animals were given extinction training to determine if the increase in within-session T_{re} was dependent on reinforced DRL performance.

Procedure

The same four animals used in Exp. 2a served. The subjects were trained at DRL 15- and 30-sec. Training at DRL 15-sec continued for 25 sessions, followed by 15 sessions

of extinction training, 15 sessions of retraining, and 10 sessions during which the animals were twice exposed to a 35°C environment. Next the animals were trained at DRL 30-sec in an identical manner and for the same number of sessions as at DRL 15-sec, except that they were given only one 35°C exposure during a three-session period. Extinction training consisted of keeping all aspects of the schedule functional, except that dispensed pellets did not enter the chamber. The stimulus conditions were identical to the S^D -Reinf. condition in Exp. 1.

RESULTS

Reliable and statistically significant increases in the within-session T_{re} were found for all animals during DRL 15-sec training. A thermal response was found for all 25 training sessions at DRL 15-sec for animals S-1 and S-2, for 17 of the 25 sessions for animal S-3, and for 24 of the 25 sessions for animal S-4. As in Exp. 1, variability in post-session T_{re} was reduced. Animal S-3's thermal response was the least reliable, but a statistically significant t was found ($t = 4.36$, $df = 24$, $p < 0.001$).

Figure 6 plots for each animal the last five sessions of DRL 15-sec training, the 15 sessions of extinction training, and the first five sessions of retraining at DRL 15-sec. Response

Fig. 6. Pre- (open square) and post-session rectal temperatures and responses per minute plotted for each animal for the last five sessions of DRL 15-sec training, 15 sessions of extinction training, and five sessions of DRL 15-sec retraining.

rate at the beginning of DRL training increased (not shown) and then decreased to approximately 3.5 responses per minute (Fig. 6). Extinction training quickly reduced the response rate and retraining restored the response rate to its pre-extinction levels within one or two sessions (Fig. 6).

Consistent within-session increases in T_{re} occurred throughout extinction training for three of the four animals (not animal S-3). Post-session T_{re} s declined for animal S-3 and S-4 as extinction training continued and were quickly restored on the first retraining day. Thus, extinction training markedly affected the response rate but had only a marginal effect on the thermal response.

EXPERIMENT 2c

One of the advantages of the adjusted percentage deprivation procedure is that it provides the experimenter with a "normally" growing subject. One disadvantage, however, is that the post-session supplementary food has to be gradually increased to maintain growth. It became obvious during DRL 30-sec training that the post-session food was approximating an *ad-libitum* meal size (*i.e.*, between 20 to 25 g). This resulted in variable performance (particularly after extinction training) and in the absence of a reliable within-session increase in T_{re} . To evaluate if the thermal response and behavior of the animals were dependent on the magnitude of the post-session supplementary food, it was decided to retrain the animals at DRL 15-sec and to modify the deprivation procedure.

Procedure

The same four animals used in previous portions of Exp. 2 served. After training at DRL 30-sec, the animals were retrained at DRL 15-sec for six sessions with the adjusted percentage deprivation still being used (*i.e.*, post-session supplementary feeding). For the next 20 days (15 sessions), all food intake was restricted to the experimental session. This was followed by six sessions in which all animals were fed 25 g, irrespective of their performance or body weight, after the experimental session.

RESULTS

Figure 7 is a plot of the body weights and T_{re} s for each animal during DRL 15-sec re-

training with the adjusted percentage deprivation procedure still functional, with food intake restricted to the experimental session, or with post-session food supplementation fixed at 25 g per session (*i.e.*, an *ad-libitum* meal size). Inspection of the figure reveals an unreliable thermal response for three of the four animals (not animal S-4) during retraining at DRL 15-sec. Restricting the food intake to the experimental session resulted in a 20% loss of body weight and an increasingly probable thermal response. Reintroducing supplementary post-session food, however, reduced the frequency and the magnitude of the within-session increases in T_{re} . DRL performance stabilized during the restricted food intake period and became unstable again during post-session supplementation. Thus, the variability observed in the T_{re} response during DRL 30-sec training appears to be related to the food intake level over a 24-hr period. The present results are informative both in terms of the conditions necessary for a reliable thermal response and for the conditions necessary for stable DRL performance. Both seem to be dependent on the difference between the total food intake prescribed by the experiment and an *ad-libitum* meal size.

The present experiment also provided a control not available during the initial adjustment to the deprivation procedure (see Exp. 2a). It was not clear whether the observed separation in pre- and post-session T_{re} s during the maintenance at the 70% body weight or increased food supplementation periods were due to simple adaptation of the animal to repeated T_{re} measures (*i.e.*, handling) or to the reasons as stated. Food supplementation was varied and the thermal response was found to covary, demonstrating that adaptation to the taking of T_{re} measures was not the cause of the thermal response.

EXPERIMENT 2d

Interresponse times and visual observations of DRL performance were collected in the present experiment to evaluate further the effect of 35°C exposure on timing behavior.

Procedure

The animals were the same subjects used in previous portions of Exp. 2. They were exposed twice to a 35°C environment at DRL

Fig. 7. Pre- (open square) and post-session rectal temperatures and pre-session body weights plotted for each animal as a function of DRL 15-sec training with the adjusted percentage deprivation procedure functional, food intake restricted to the experimental session, and post-session food supplementation increased to 25 g.

15-sec, with five sessions at 25° C intervening, and once at DRL 30-sec.

Visual observation of DRL performance in both 25°-C and 35°-C environments was performed by closed-circuit television. DRL performance at 25° C was observed over a number of training sessions by two or more

observers. Initially, agreement was established between observers that each animal engaged in a characteristic behavior during the interval between responses. Further observation established what sequence of movements best described this behavior. Included in this definition of an "overt" behavior was the require-

ment that the animal move away from the lever and return to it between presses. Consecutive responses which occurred without the animal leaving the lever (*e.g.*, bursts of short IRTs), or overt behaviors which did not consist of the characteristic sequence of movements, were observed as "other behaviors". Following agreement between observers, a single observer classified all the behaviors between responses into two classes (*i.e.*, overt or other) for an entire session for DRL 15-sec performance at 25° and 35° C.

RESULTS

The data to be discussed consist of the second 35°-C exposure at DRL 15-sec, where both the thermal response and DRL performance were stable (see Exp. 2b). Exposure to the 35°-C environment had the same effect on response rate, reinforcement rate, and T_{re} as was observed in Exp. 1. Response rate reduced from a mean of 3.7 responses per min-

ute for the session before 35°-C exposure, to a mean of 1.08 responses per minute for the 35°-C session. The mean response rate for the session-after 35°-C exposure increased to 3.9 responses per minute, again demonstrating the reversibility of the 35°-C exposure. The mean reinforcements per session varied from 240 to 61 to 224 for the three-session period. The mean post-session T_{re} increased from 38.87° C to 39.36° C and then reduced to 38.50° C for the three-session high ambient temperature exposure. Thus, the present experiment replicated the results of Exp. 1.

Plotted in Fig. 8 are the IRT distributions for the session-before, session-of, and session-after exposure to the 35°-C environment for all four subjects. The relative frequency per IRT interval was calculated on the basis of the total frequency of IRTs for all 10 intervals, with the tenth interval including all IRTs greater than 27 sec. Inspection of the figure reveals that the modal IRT interval

Fig. 8. The relative frequency of IRTs, in 3-sec intervals, plotted for each animal for the session-before, session-of, and session-after high ambient temperature exposure. The tenth interval includes all IRTs greater than 27 sec. The arrow marks the contingent IRT (*i.e.*, IRTs greater than 15 sec).

for each animal at the 25°-C exposures was the sixth interval (animal S-1 for the session-before the 35°-C exposure was an exception) which consisted of IRTs greater than 15 sec but smaller than 18 sec. Exposure to 35° C increased the proportion of IRTs above the contingent IRT (*i.e.*, greater than 15 sec) with a noticeable increase in IRTs greater than 27 sec. Thus, exposure to the 35°-C environment reduced the response rate and reinforcement rate, but increased the time between responses. These effects were again time-dependent (see Fig. 3) with IRTs increasing as the session progressed.

Table 2

Frequency of behaviors which occurred during the interval between responses for DRL 15-sec performance at 25° C and 35° C.

Animal	Behaviors	Responses	
		25° C	35° C
S-1	Rail biting	223	48
	Other behaviors	52	34
	TOTAL	280	82
S-2	Food-cup	290	42
	Other behaviors	60	66
	TOTAL	350	108
S-3	Circling	33	58
	Other behaviors	184	34
	TOTAL	217	89
S-4	Tail-rail biting	117	32
	Other behaviors	111	59
	TOTAL	228	91

Visual observation of the animals at 25° C quickly revealed that each animal did indeed engage in characteristic behaviors during the interval between responses. Animal S-1, for example, would bite one of the rails which made up the floor of the chamber. At 25° C, 223 of the 280 (80%) of the recorded overt behaviors consisted of rail biting. At 35° C, the frequency of such characteristic overt behaviors reduced to 48 of 82 recorded behaviors, whereas the frequency of non-characteristic behaviors remained at about the same level observed at 25° C (Table 2). Animal S-2's data also fits this description, whereas animal S-4 showed reductions in both categories of behavior. Observation of animal S-3 at 25° C suggested that it circled slowly around the chamber between responses, but on the day selected for data collection it remained in or near the food cup. Comparison

between ambient temperature conditions for this animal could therefore not be made. For the three remaining animals, the probability of the non-characteristic overt behaviors increased as the session progressed at 35° C. These behaviors at 35° C included sitting inactively for the required period, attempts at escape, or saliva spreading. Thus, it appears that exposure to a high ambient temperature reduced the frequency of the characteristic overt behavior and elicited a different set of behaviors than those found at 25° C, some of which have been shown to be functional in minimizing the hyperthermia resulting from 35°-C exposure (Hainsworth, 1967; Robinson, Blatt, and Teplitz, 1968).

GENERAL DISCUSSION

The second experiment demonstrated that the increases in T_{re} occurring during DRL performance were dependent on the deprivation procedure. Figures 5 and 7 suggest that a moderate food intake level per day was the necessary and sufficient condition for the within-session increase in T_{re} . If the total food intake approximated an *ad-libitum* meal size, or if food intake was minimal (*i.e.*, 5 g or less per day), then the within-session increase in T_{re} became unreliable. To the extent that stable DRL performance was also dependent on the deprivation procedure, then DRL performance and the thermal response covary.

The results of the first and second experiments demonstrated that manipulation of DRL performance does not affect the thermal response. Extinction training in the second experiment rapidly reduced response rate for all animals but had no consistent effect on the thermal response. Increases in the DRL value in the first experiment reduced response rate and reinforcements per session but also had no differential effect on the thermal response. Thus, neither the existence of DRL performance nor changes in DRL performance were necessary conditions for changes in the thermal response. The relationship between T_{re} changes and DRL performance would, therefore, appear to be incidental.

This conclusion, however, is not to be extended to all schedules of reinforcement; Hamilton (1963) and Hamilton and Brobeck (1964) found increases in the within-session change in T_{re} as fixed-ratio size increased,

while Barofsky and Hurwitz (1968) found increases in the T_{re} change when the intensity of electric shock was increased during discriminated avoidance performance. The significance of any covariation between the thermal response and performance varies then as a function of the schedule of reinforcement.

Although manipulation of DRL performance does not affect the thermal response, manipulation of the thermal state of the animal does affect DRL performance. Decrements in DRL performance were found in both experiments when the animals were exposed to a 35°C environment. Post-session T_{re} s, after the 35°C exposure, were higher than expected (relative to post-session T_{re} s at 25°C) for seven of the eight subjects.

Hainsworth (1967) found for untrained, undeprived animals, that T_{re} increased from 37.9° C to approximately 39.6° C within 30 to 60 min of exposure to a 36°C environment. The T_{re} remained within a 0.1° C of this level for the remainder of a 4-hr session. The hyperthermia observed in the 35°C environment of the present experiment, therefore, would be expected simply as a product of high ambient temperature exposure independent of training, deprivation, or food consumption. The observation by Hainsworth (1967) that the hyperthermia developed within 30 to 60 min correlates with observations that decrements in DRL performance developed within 40 to 50 min. This suggests that the decrements in DRL performance were a direct response to the developing hyperthermia.

Support for this conclusion comes from the observed changes in the pattern of responding during DRL performance. Figure 8 demonstrated that the 35°C exposure increased the proportion of long IRTs. Inspection of cumulative records revealed that the probability of a long IRT increased with time in the 35°C environment. Visual observation of the overt behaviors demonstrated, in the second experiment, that continued exposure to the 35°C environment increased the probability of saliva spreading, escape attempts, and periods of inactivity.

The stimulus for these alternative behaviors appears to be the developing hyperthermia and the maintenance of these behaviors

appears to be related to their thermal consequence. Saliva spreading, for example, has been shown to be necessary for survival at high ambient temperature (Hainsworth, 1967) and non-exercise has been shown to be adaptive under conditions where exercise would be fatal (Robinson *et al.*, 1968).

The modifications in DRL performance at 35° C are therefore instrumental responses which have thermoregulatory consequences. The reduced food intake (Hamilton and Brobeck, 1964), reduced spontaneous motor activity (Stevenson and Rixon, 1957), and increased stabilimeter activity (Hainsworth, 1967) observed in high ambient temperatures reflect the alternative behaviors elicited by hyperthermia.

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