**OPERANT STIMULUS CONTROL APPLIED TO MAZE
BEHAVIOR: HEAT ESCAPE CONDITIONING AND
DISCRIMINATION REVERSAL IN ALLIGATOR
MISSISSIPPIENSIS¹**

ROBERT S. DAVIDSON, JR.

FLORIDA STATE UNIVERSITY²

Eight alligators were trained to escape heat by traversing an 8-ft runway containing right or left approaches to a water tank. All subjects were run until they had satisfied three criteria of stable response time, after which the predominant escape path was blocked, requiring discrimination reversal. Seven subjects again met the criteria; three also met them in a second reversal.

Studies of maze behavior have traditionally employed group-statistical methodology in which several subjects are run for a predetermined number of trials or until some response measure reaches asymptote. As Sidman (1960) has indicated, greater methodological refinement might be obtained by requiring single subjects to stabilize behavior at a baseline rate against which the effects of variables can be directly measured.

Yerkes (1903) employed a version of this approach in assessing the maze learning of frogs and crawfish. The maze was a straight alley type with a partition near the goal end dividing the alley into two paths, either of which could be blocked by a glass cul-de-sac.

A similar apparatus was used in the present study of maze learning in the alligator.

METHOD

Subjects

Eight American alligators (*Alligator mississippiensis*), seven 30-42 in. and one 20 in. long, were maintained for 15 months on a weekly feeding of approximately 400 minnows (*Notemigonus crysoleucas*) offered in an 8 by 2 by 2 ft water tank. Subjects had constant access to an 8-ft half-round wooden platform,

via two ramps from the water tank. Temperature in the living space was maintained from 75 to 85 degrees F (basking range for some reptiles; Goin and Goin, 1962). All subjects appeared to be in good health although one died during the experiment. Each was weighed two to five times per month.

Apparatus

A large plywood alley, 8 by 4 ft by 26 in. deep, was painted flat black. The floor plan is shown in Fig. 1. A 3.5 by 2 ft high partition divided the approach to the goal into two paths. A 4 by 4 by 1 ft deep galvanized water tank filled with water 70-80 degrees F was attached as the goal. Several 4 by 2 by 1 ft hardware cloth cages were designed to fit, two at a time, into the goal tank and one in start box position. This facilitated semi-automatic handling of the subjects.

Three 250-w infrared heat lamps were installed 2 ft over the start box and six more were placed at the same height and at equal distances over the length of the maze floor. The room temperature was maintained at 90 to 94 degrees F which, with heat lamps on, raised the maze floor temperature to 105 degrees F (lethal limits of some reptiles start at about 110 degrees F, according to Goin and Goin, 1962).

An overhead mirror was installed above the maze, enabling subjects to be observed from an adjoining room without interfering with ongoing behavior.

Procedure

A series of pilot studies was conducted to isolate procedures that would generate consistent and stable maze running. Periods of

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²Reprints may be obtained from the author, Veterans Administration Hospital, Psychology Laboratory, Coral Gables, Florida 33134.

restraint, lighting gradients, auditory stimulation, 18 weeks of food and water deprivation with food offered at the goal and aversive heat confined to the start box were all unsuccessful in accomplishing this. However, a procedure using aversive heat over the entire maze floor and spaced trials (one per day) did produce stable escape responses.

The experiment proper, using the pilot study subjects, was designed as follows: the experimental space was maintained at 90-94 degrees F and nine heat lamps irradiated the start box and maze floor, which kept the floor at about 105 degrees F.

On each trial during training, the subject was guided into one of the hardware cloth cages, carried to the maze room and placed in the heated start box with free access to the heated maze (the guillotine door at the front of the start box was removed). The experimenter then retired to the observation room to record responses. No cul was present during training, so that subjects could enter the goal via either side of the partition.

Fig. 1. Maze floor plan. Key: GT=goal tank; C=cages; b=Plexiglas block; P=partition; MF=maze floor; and SB=start box.

Pilot work had revealed that the aversive property of the heat lamps was considerably reduced when the subjects' skins were wet, so they were maintained in a dry state (thus deprived of food and water) until run. Two freshly killed fish were available in each goal tank and subjects were left in the goal tank 5 min. Because feeding had little effect in the preliminary experiments, it was felt that this would not confound the influence of the controlling variables. This allowed subjects to be maintained without separate feedings and consequent skin wetting.

On each trial, the following measures were recorded: response time, running time, number of errors (responses to the non-preferred side), and number of pauses (immobility or lying down longer than 3 sec). Response time was defined as the time from which the subject's tail crossed a threshold at the start box until the goal tank was entered with all four legs. Running time was defined as response time minus time engaged in competing responses (*i.e.*, time spent only in locomotion toward the goal). Running times and pauses were not recorded during the training period, since techniques and criteria for their measurement were developed at that time. Also recorded were maze response maps showing the paths taken to reach the goal on each trial, and the location and duration of pauses and errors.

Trials were continued until response times met three criteria of stability: 10 consecutive trials in which the means of the first and second blocks of five trials fell within 5% of the 10-trial mean; less than 90 sec response time on each trial; and eight or more responses to one side of the partition (the preferred path). These criteria were imposed to define a baseline against which to test the effects of the independent variable (reversal). The first criterion was taken from Sidman (1960); the second was chosen because it defined the upper limit of time taken to traverse the maze without competing responses; and the third constituted a refinement of Yerkes' (1903) criterion.

After the criteria were met, a Plexiglas cul-de-sac was placed in the preferred path until behavior met the stability criteria responding to the other side. At this point one subject (#8, the smallest) died. Three of the remaining seven subjects which completed training and

one reversal within 10 weeks were also run through a second discrimination reversal.

After this was completed, all subjects were run through 17-21 additional trials to determine the durability of aversive control versus the control (if any) exerted by food reinforcement without heat. Subjects were returned to the maze in the absence of heat lamps and cul with fish again offered at the maze goal for several trials. The final phase comprised several more trials with heat lamps on but no food deprivation. If, in either of these two conditions, the subject did not leave the start box within 20 min (the longest time taken under any previous condition), the animal was removed. Though the number of reversals differed between them, all seven animals had similar histories in terms of the total number of trials (range = 71-90).

RESULTS

Figure 2 depicts the obtained response and running times for a typical subject (#4). The open circles represent response time curves, while the filled circles (lower curves) plot the curves for running times. Vertical lines separate the curves into experimental conditions.

During reversal learning, introduction of the cul increased response times followed by negatively accelerated functions. By the time the stability criteria had been reattained, response times had decreased and appeared to peak very near the running time curves, which showed very little fluctuation. Similar data were obtained from all subjects.

The results during the last two conditions were less orderly. Subject #4 (Fig. 2) showed some extinction-like behavior, *e.g.*, longer and

Fig. 2. Response and running times on each trial, for subject #4. No block was present in the Free (training) Period, nor in the last two conditions (Heat Lamps Off and On). Fish were present at the goal during "Heat Lamps Off." During "Heat Lamps On," free feeding was provided in the home tank but not in the maze goal.

more variable response times and a tendency towards increasing response times when heat lamps were off and fish were available. This subject did not respond on 25% of the heat lamps off trials. Criterion time responses once again increased in the final phase. This effect was also shown by the other subjects.

Qualitative analysis of recorded maze response paths indicated that two classes of competing responses (pauses and errors) were primarily responsible for long response times and for most of the variability during escape conditioning. By the time each subject approached criterion performance in each condition, these responses were either greatly reduced in frequency or eliminated.

Quantitative analysis of pauses and errors required grouping of the individual data, since errors were often dichotomous (1 or 0) and pauses were distributed into a limited number (0-4) per trial. Consequently, pause and error scores were grouped using the Loucks modification of the Vincent grouping technique (Loucks, 1931), yielding mean curves that were comparable between all conditions.

Error functions (responses to the non-preferred side) revealed negative acceleration during reversal periods, as shown in Fig. 3. These curves were roughly similar in form to the response time functions of reversal periods in Fig. 2. For each subject, errors were virtually eliminated by the beginning of each criterion period.

Figure 4 illustrates pause functions in all experimental conditions except the training period. Again the form of the functions during reversals was an initial increase followed by negatively accelerated curves. On criterion trials and in the final condition with heat lamps on, subjects tended to make one pause per trial. Pauses were much more frequent immediately after reversals and during the period with heat lamps off, when twice as many pauses per trial were observed. These observations held for each subject and for the group.

To determine whether consumption of fish exerted any significant positive reinforcement over behavior in the maze, it was assumed that the immediate effect should appear on the next trial. Therefore, the relationship between the number of fish consumed and the response time on the next trial was computed via a X^2 contingency table. No significant relationships were found, either for single subjects or over all trials ($C = .107$, $X^2 = 4.99$, $df = 4$, $p > .05$). The raw data showed erratic fish consumption (ranging from 23-88% of opportunities, for single subjects), with no apparent relationship to escape behavior.

Some statistical comparisons between the heat lamps on and off conditions were made for the same purpose. A significantly greater number of response times less than 90 sec ($t = 5.58$, $df = 6$, $p < .05$) and significantly fewer pauses ($t = 2.79$, $df = 6$, $p < .05$) oc-

Vincentized Errors

Fig. 3. Vincentized errors. Each point on the graph represents mean number of errors per trial, by Vincent tenths of trials to end of criterion.

Vincentized Pauses

Fig. 4. Vincentized pauses. Each point on the graph represents mean number of pauses per trial, by Vincent tenths of trials to end of criterion.

curred in the heat lamps on than off conditions.

DISCUSSION

Of several conditions employed in an attempt to generate stable maze escape behavior, only aversive heat stimulation was effective with alligators. The use of the baseline methodology (Sidman, 1960) enabled a systematic analysis of the effect of independent variables on the escape conditioned response. The predictable approach to criteria in 10-37 trials on 18 separate occasions and the replicability of criterion performance demonstrated the reliability of maze escape behavior under these conditions.

This finding was related to the manner in which the escape response was acquired. Several analyses of escape behavior of single subjects and of groups indicated that competing responses of two classes (errors and pauses) occurred with high probability early in each learning period. Gradually their frequency

decreased until each subject tended to follow the same path to the goal with either no pauses, or one pause at approximately the same location, and no other competing responses.

Since all competing responses contributed to total response time on each trial, the response time curve might be expected to show a function similar to that for errors and pauses. All three types of curves were negatively accelerated. These results substantiate the suggestion by Pereboom and Crawford (1958) that competing responses are reduced as a function of reinforced trials, thus accounting for a major portion of the variability. Once these have been eliminated, subjects can be seen to run at fairly constant speeds.

Although food and water deprivation and opportunity to consume fish were used as an adjunct in the present study, several behavioral and statistical analyses demonstrated that these conditions exerted little control over heat escape behavior or approach behavior itself (in preliminary work). Consumption of

fish occurred very irregularly in each subject and bore no relationship to heat escape behavior. Other investigators (*e.g.*, Morgan, 1964) have mentioned the lack of control of crocodilian behavior provided by food deprivation (which can be endured for months at a time) and reinforcement.

Other variables seemed to contribute to stimulus control over heat escape behavior. Though not systematically explored, distributing trials over a 24-hr intertrial interval decreased response time variability more than did massing trials. In addition, as long as subjects were picked up manually, they struggled violently and revealed unstable maze behavior. The use of hardware cloth cages for transporting them to and from start box and goal positions led to greater stability.

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